PETROGENESIS OF THE TASMANIAN GRANITOIDS

by

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Except as stated herein this thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and that, to the best of the candidate's knowledge and belief, this thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text of this thesis.

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ABSTRACT

This study of Tasman Orogenic Zone granitoid rocks in Tasmania is mainly concerned with the petrogenesis of a suite of garnet- and cordierite-bearing, aluminous granites. These granites and the associated hornblende-biotite granodiorites are contact-aureole plutons of Devonian age, emplaced in paratectonically deformed Palaeozoic rocks.

The garnet- and cordierite-bearing granites are highly aluminous, have a restricted range of SiO_2 contents (70-76 percent), high K_2O/Na_2O ratios and low Na_2O, FeO, MgO and CaO contents. The granodiorites have a wider range in SiO_2 contents (60-72 percent) and higher Na_2O, FeO, MgO and CaO contents. The compositions of mafic phases are specific to each pluton. Euhedral to subhedral garnets in the aluminous granites are almandine- and pyrope-rich, with grossular and spessartine components totalling less than 5 mole percent. The primary biotite, which is compositionally distinct from subsolidus biotite replacing garnet and cordierite, is Fe- and Al-rich (octahedral Al contents 0.8 - 1.1). Cordierite has Mg/(Mg+Fe) ratios ranging from 0.18 to 0.64. Core compositions of plagioclase in the aluminous granites are in the range An35-An50.

The stability fields of the mafic phases define the early crystallization history of the garnet- and cordierite-bearing granites. At pressures less than ∿10 kb., the assemblages garnet-biotite, garnet-cordierite-biotite and cordierite-biotite represent progressively lower equilibrium pressures for near-liquidus phase assemblages at temperatures in the range 800 - 900°C (Green, 1976). Cooling, probably during ascent, is recorded by zoned garnets. The lack of primary muscovite suggests that most of the granite plutons completed crystallization high in the crust, at pressures

less than 2-3 kb.

Strontium isotopic analyses of the granitoid plutons in eastern Tasmania yield ages from 400 to 370 m.y. Initial Sr^{87}/Sr^{86} ratios for the granites range from 0.705 to 0.714, whereas 0.705 to 0.708 is the range of initial ratios for the granodiorites. A few oxygen isotopic results for pervasively altered biotite granites are consistent with a magmatic source for the hydrothermal fluids that caused their alteration.

Field, mineralogical and compositional data all emphasise the individuality of each pluton. Field and strontium isotopic data suggest that their compositions are little modified by assimilation and there is little evidence for a genetic relationship between plutons. The Tasmanian granitoid plutons are considered to have crystallized from separate magmas each derived by partial melting of different source rocks. A pelitic crustal source for the aluminous granites is supported by high initial Sr^{87}/Sr^{86} isotopic ratios, by highly siliceous and aluminous compositions and by the stability fields of mafic phases. A mafic igneous, crustal source for the granodiorites is supported by relatively low initial Sr^{87}/Sr^{86} isotopic ratios, by major oxide compositions which are richer in Na_2O and CaO than the aluminous granites, and by the occurrence of distinctive hornblende-biotite diorite inclusions, which are interpreted as relict blocks of source rock.

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PART I

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Tasman Orogenic Zone

The Tasman Orogenic Zone (Solomon and Griffiths, 1972, 1974) is a mainly Palaeozoic, continental margin mobile zone extending along eastern Australia from Queensland to Tasmania, and into Antarctica (Figure 1.1). This zone, some 4500 km. long and up to 1000 km. wide, is flanked on its western margin by older Precambrian rocks and on its eastern margin in New Zealand and New Caledonia by Mesozoic rocks. Continental crustal areas such as the Lord Howe Rise and South Tasman Rise, although now submerged, are also considered to be part of the Tasman Orogenic Zone (Griffiths, 1971, 1974). The sequence of events in the Tasman zone is complex, with the geological history spanning the whole of the Palaeozoic. Several smaller areas can be distinguished including the New England, Lachlan and Ross Orogens which have distinct, but partially overlapping, geological histories. Events tend to become younger to the north and continue into the Mesozoic in the New England Orogen (Leitch, 1974). In Tasmania, at the southern end of the Lachlan Orogen, the geological history spans the Palaeozoic.

Granitoid plutons in the Tasman Orogenic Zone range in age from Cambrian near the western Precambrian margin (White et al., 1967; Compston et al., 1966; Dasch et al., 1971) and in the Ross Orogen (Laird et al., 1972), to Lower Triassic in the New England Orogen (Leitch, 1974). Most of the plutons range in age from Siluro-Devonian in the southern Lachlan Orogen to Carboniferous-Permian in the New England Orogen. In general, the granitoids were intruded during and following the final phases of regional deformation. White et al. (1974) estimate that the granitoids outcrop over slightly less than 25 percent of the total area of the Tasman zone. Of the exposed Palaeozoic rocks in north-eastern Tasmania, 60 percent of the outcrop is granitoid

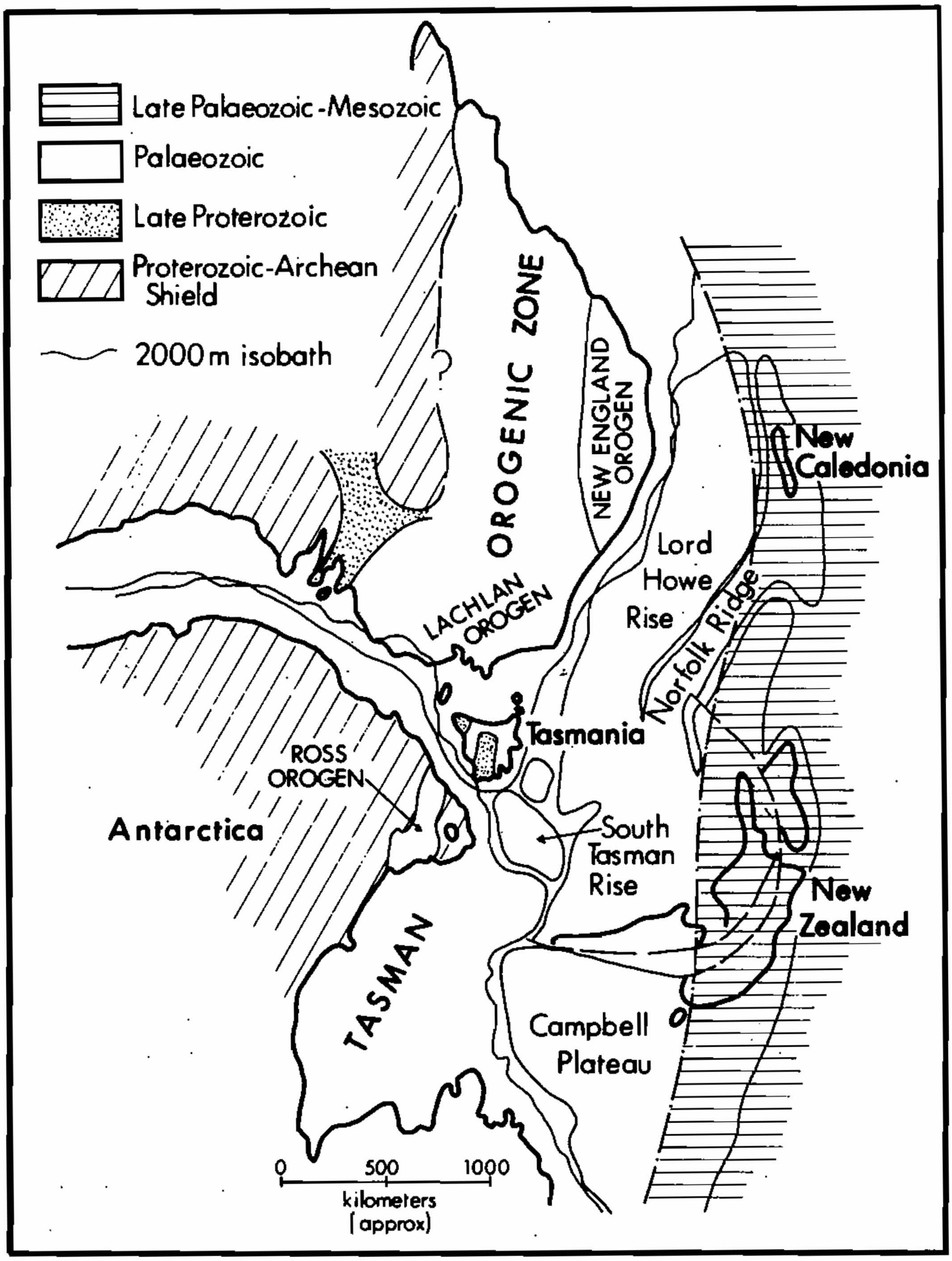


FIGURE 1.1. Pre-Mesozoic reconstruction of the Tasman Orogenic Zone (after Griffiths, 1971, 1974).

rock. Consequently the granitoids are a significant component of the Tasman Orogenic Zone, similar to other Circum-Pacific continental margin mobile zones.

Other major lithological elements in the Tasman Orogenic Zone include Cambrian to Permian sediments (predominantly greywackes and shales), volcanic chains (Leitch, 1975; Solomon and Griffiths, 1974) and belts of ultramafic rocks (Crook and Felton, 1975). All these have undergone varying degrees of burial metamorphism and low-pressure regional metamorphism (andalusite-sillimanite type - Miyashiro, 1974), mostly at relatively low grades (Vallance, 1967; Guy, 1968; Smith, 1969; Leitch, 1974). A significant feature of the Tasman zone is that the areas of high-grade metamorphic rocks often have associated migmatites and a suite of highly aluminous, silica and potassium-rich granitoid plutons (Vallance, 1967; White et al., 1974).

Because granitoids form such a large volume of the crust of the Tasman zone, they must be considered as an integral part of the tectonic framework and geological history. Granitoid plutons also have a particular role in establishing both the relative and absolute timing of events in the mobile zone.

1.2 Previous Work on Tasmanian Granitoids

The main exposures of the Devonian (Carboniferous) granitoid plutons of Tasmania are shown in Figure 1.2 and the principal rock types in each exposure are given in Table 1.1, together with references. The most detailed studies have been carried out on the altered biotite granites, including the Heemskirk, Blue Tier, Meredith and Ben Lomond Granites, which are associated with primary and secondary cassiterite deposits. Many of these studies concentrated only on the field aspects of the granitoids, and some of the plutons, such as Granite Tor, Housetop Granite and Coxs Bight, are only scantily described. Relatively little attention has been paid to the petrogenesis of the granitoids as a whole, although in his wide ranging study of the Blue Tier Batholith, Groves (Gee and Groves, 1971; Groves, 1972b,c,in press) briefly considered some aspects of the

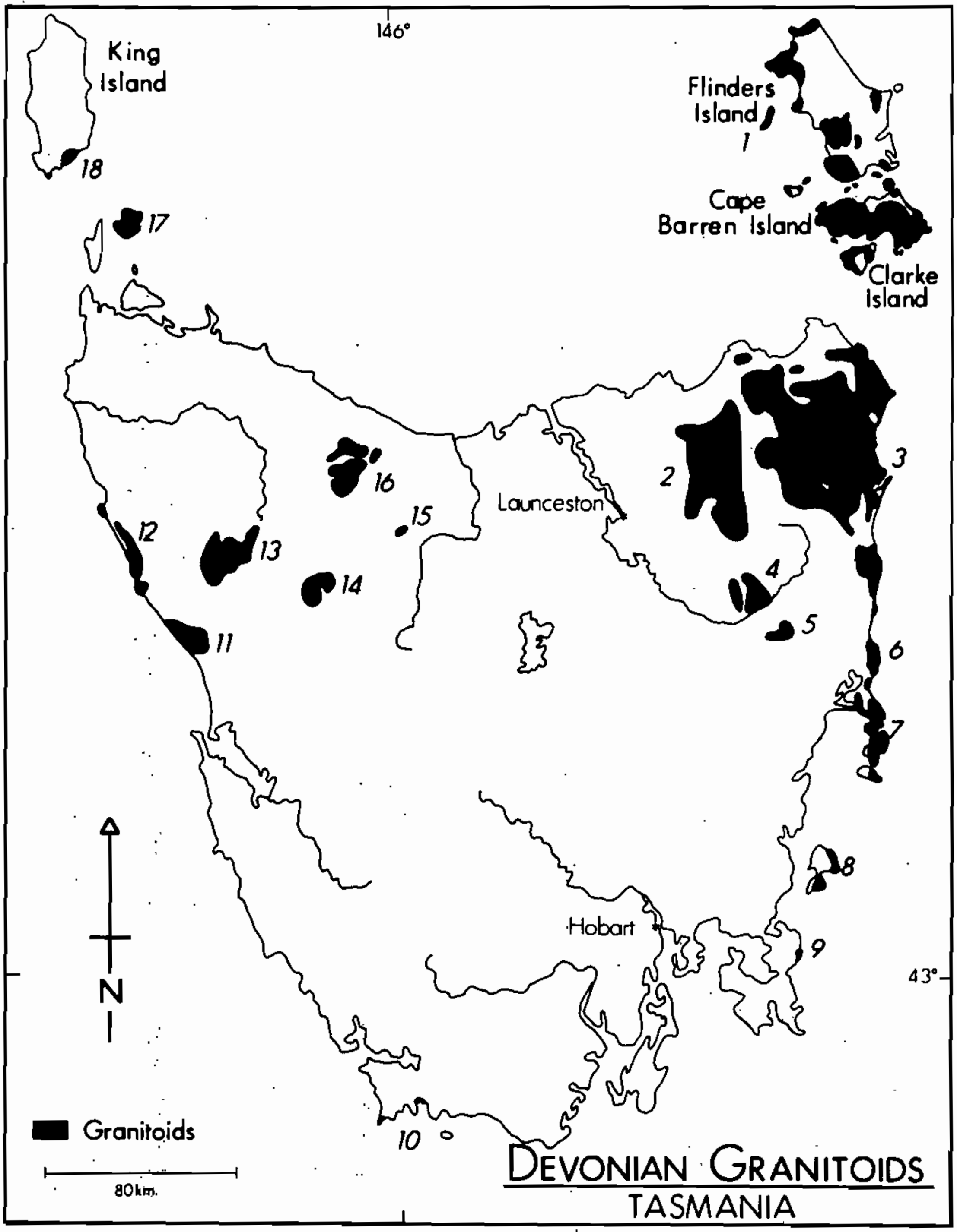


FIGURE 1.2. Distribution of the Devonian granitoids in Tasmania after Banks (1965) and this work. Numbers refer to granitoid exposures listed in Table 1.1.

Table 1.1

DEVONIAN GRANITOIDS, TASMANIA

Granitoid Exposures	Rock Types	References
	EASTERN TASMANIA	
1 Furneaux Islands	GT-Cord-BT and BT granites, HB-BT granodiorites and altered BT granites	Blake, 1947; Groves, 1973; this work.
2 Scottsdale Batholith	HB-BT and BT granodiorites	Longman, 1966; Marshall, 1969; McClenaghan and Baillie, 1975.
3 Blue Tier Batholith	GT-Cord-BT and BT granites, HB-BT granodiorites and altered BT granites	Gee and Groves, 1971; Groves, in press; McClenaghan and Baillie, 1975; this work.
4 Ben Lomond Granite	BT granites and altered BT granites	Blissett, 1959.
5 Royal George	BT granites and altered BT granites	Beattie, 1967.
6 Bicheno Granite	GT-Cord-BT granites and altered granites	This work.
7 Freycinet Peninsula	BT granites, altered BT granites and HB-BT granodiorites	Groves, 1965; this work.
8 Maria Island	Altered GT-BT granites	This work.
9 Forrester Peninsula	BT granites	Jennings, 1974.
	WESTERN TASMANIA	
10 Coxs Bight and South West Cape	Altered BT granites	D.J. Jennings, pers. comm.
11 Heemskirk Granite	Altered BT granites	Blissett, 1962; Brooks and Compston, 1965; Klominský, 1971; Groves, 1972a.
12 Pieman Heads Granite	BT granites and altered BT granites	Brooks, 1966a.
13 Meredith Granite	BT granites	Brooks, 1966a; Groves, 1972a; Stockley, 1972.
14 Granite Tor	BT granites	McDougall and Leggo, 1965.
15 Dolcoath Granite	BT granites	Webb, 1974.
16 Housetop Granite	BT granites and altered BT granites	Mills, 1971.
17 Three Hummock Island	BT granites	McDougall and Leggo, 1965.
18 Grassy Granite	BT granites	McDougall and Leggo, 1965.

GT - garnet; BT - biotite; Cord - cordierite; HB - hornblende.

origin of the magmas, as well as the composite nature of the batholith, the mechanisms of intrusion, the geochemistry and the associated mineralization. Previous isotopic studies of the granitoids are limited to those of McDougall and Leggo (1965) and Brooks (1966a,b), whose results provide a broad outline of the ages of the granitoids and a detailed geochronology for the Heemskirk Granite.

1.3 Theories of Granitoid Rock Genesis

Much of the emotion surrounding the discussion of the origin of granitoid rocks has disappeared with recognition that granitoids of similar textures and mineralogies may have formed by a variety of processes. This cooling down was linked to advances in the experimental knowledge of simplified 'granite' systems (Tuttle and Bowen, 1958), of the partial melting behaviour of crustal rocks (Winkler, 1976) and of the measurement of rates of diffusion (Fyfe *et al.*, 1958; Foland, 1974). Four main groups of processes that may be considered as contributing to the generation of both intrusive and extrusive calc-alkaline rocks are:

1. Anatexis of the upper mantle and lower crust
2. Differentiation of basaltic and near-basaltic melts
3. Hybridization
4. Granitization

The first process is currently considered to be the most important within the constraints of the field, chemical and experimental evidence. The composition of the melt is primarily controlled by the composition of the source rocks undergoing melting and the pressure, temperature and f_{H_2O}, and may be modified by differentiation and assimilation during intrusion. The source rocks for the island-arc calc-alkaline series are upper mantle rocks or mixtures of oceanic lithosphere and upper mantle rocks. On continental margins crustal as well as mantle derived magmas are thought to be significant, as large volumes of the melts are more siliceous than those in the island arcs.

Temperatures required to produce completely liquid calc-alkaline melts, having low water contents, are probably unattainable in the lower crust with a continental geothermal gradient which is consistent with generally accepted geothermal models (Ringwood, 1975). Consequently anatexis in the lower continental crust is probably induced by transient heat sources (Presnall and Bateman, 1973). The field and chemical characteristics of the Tasmanian granitoids are consistent with their generation by anatexis of different source rocks in the lower crust.

The second and third processes, although giving rise to rocks with calc-alkaline compositions, are not currently widely considered to produce a large proportion of the granitoid plutons. A melt may assimilate any other rock type by partially melting or reacting with the included material, depending on the heat and fluids available, or by disrupting the included material. Based on composition studies assimilation is fairly limited, although hybridization of a low temperature granitic melt through assimilation of a mafic rock might be difficult to distinguish from a partial melt with relict crystals of the mafic precursor.

The genesis of granitoid rocks without the participation of a melt phase is probably not significant for the bulk of granitoid rocks which, where undeformed, have intrusive field relations. Even in the lower crust at magmatic temperatures, rates of diffusion are too slow within a geological time framework (Fyfe et al., 1958). Infiltration metasomatism, which may have the potential for transporting fluid components over significant distances in reasonable geological times (Fletcher and Hofmann, 1974), also has a limited role, as this process tends to reduce the number of phases in a pre-existing rock (Korzhinskii, 1970), rather than form a multiple phase rock (for example a granodiorite). Also the mineralogy of some granitoids suggests that the P_{H_2O} of the rock was buffered at low values, and low water contents are not consistent with large scale fluid movement. Granitization appears to be restricted to igneous contact effects where expelled magmatic fluids react with country rocks.

The following features of Palaeozoic granitoid plutons in eastern Australia should be accounted for by any petrogenetic model:

a) The plutons occur within intrusive sequences as mappable units which have relatively restricted compositions and mineralogies.

b) Subvolcanic plutons are comagmatic with extruded volcanics. Plutons which have crystallized at deeper crustal levels, at temperatures greater than or similar to the country rock, have compositions broadly similar to those of calc-alkaline lavas.

c) The mechanism of intrusion varies with depth in the crust and the plutons may be pre-, syn-, or post-tectonic.

d) Taken as a whole there is a broad range in granitoid rock major and minor element contents and isotopic compositions.

1.4 Aims of this Investigation

This thesis is primarily concerned with the petrography, isotopic characteristics and petrogenesis of a suite of markedly aluminous garnet-cordierite-biotite granites which has been distinguished by the author in eastern Tasmania. It is based on existing regional mapping and on new mapping in the Furneaux Group and the Bicheno area. The main aims of the thesis are:

1. To outline the petrogenesis of the garnet-cordierite-biotite granites. These rocks are of particular interest because, as will be shown, they are reworked continental crust and their crystallization conditions, which are well defined by their mafic mineral stabilities, provide an insight into the pressure, temperature and f_{H_2O} conditions of the lower crust.

2. To compare the Sr and O isotopic compositions of the altered granites with the unaltered granitoids and further establish the model for the metasomatism and greisenization of the altered rocks.

3. To map the regional geology of the southern part of the Furneaux Group with emphasis on the granitoid plutons.

The granitoids will be discussed in Part II of this thesis in terms of their field relationships, their petrography, and their mineral and whole rock compositions, with emphasis on the garnet- and cordierite-bearing granites. Field relationships for the granitoids in the Furneaux Group and the St. Helens area are given in Appendices E and H. In Part III, the Sr and O isotopic compositions of the three groups of granitoids are considered, and the Sr isotopic composition of the Mathinna Beds country rock is outlined. A petrogenetic history for the Tasmanian granitoids is presented in Part IV.

1.5 Classification and Terminology used in this Thesis

Streckeisen's (1973) plutonic rock classification is used in this thesis. 'Granitoid' collectively refers to alkali-feldspar granites, granites, granodiorites and tonalites. The granitoid bodies are termed plutons when individual intrusions have been distinguished on the basis of a common mineralogy in all textural variants, and of relatively simple external contacts either with sedimentary country rocks or other granitoids. Krauskopf (1968) has drawn attention to the difficulties in defining separate plutons. In newly mapped areas where areal extent, textural variants and mineralogy of a pluton are well known, the pluton has been given geographical and rock type names (for instance the Mt. Kerford Granite). Terms which are established in the literature and comprise geographical and rock type names, such as the Heemskirk Granite, have been retained in this thesis. When grouped together, with a total area in excess of 100 $km.^2$, the pluton group is referred to as a batholith.

On a larger scale the Tasmanian granitoid plutons, which generally have narrow, less than 500 m. wide, contact metamorphic aureoles, may be classified as contact-aureole granitoids, after White et al. (1974). Subvolcanic and regional-aureole granitoids are not exposed in Tasmania, but occur in granitoid terrains further north in the Tasman Orogenic Zone.

1.6 Locations and Samples

The outcrop of all Devonian (Carboniferous) granitoids in Tasmania is shown in Figure 1.2, and geological maps of those plutons studied in detail are given in Figures 2.1, 2.2, 3.1 to 3.3, 9.4 and E.1 to E.3. The nature and location of samples discussed in the text are given in Appendix A.

PART II

GEOLOGY, PETROGRAPHY AND CHEMICAL COMPOSITION

OF THE

TASMANIAN GRANITOIDS

CHAPTER 2

INTRODUCTION

2.1 Three Groups of Granitoids

In this thesis the mafic mineral assemblage, which is characteristic for individual granitoid plutons, is the basis for the distinction of the three groups of Tasmanian granitoids: the garnet-cordierite-biotite granites, the biotite granites (including the altered biotite granites) and the hornblende-biotite granodiorites. Included within the garnet-cordierite-biotite granites are the mafic assemblages garnet-cordierite-biotite, garnet-biotite and cordierite-biotite. The biotite granites and the garnet-cordierite-biotite granites are the most common rock types in the granitoid terrains, whereas hornblende-biotite granodiorite is the least common and is restricted to north-eastern Tasmania (Figure 1.2, Table 1.1). The garnet-cordierite-biotite granites form some 30 percent of the exposed granitoid rocks in north-eastern Tasmania (Figure 2.1). Within the Blue Tier Batholith (Figure 2.2) only three plutons (10% of the area) carry garnet and cordierite, but in the southern Furneaux Group (Appendix E) half the plutons (70% of the granitoid outcrop) are characterized by these phases. No garnet- or cordierite-bearing rocks have been recorded from the Scottsdale Batholith, Ben Lomond and Royal George Granites or from granitoids in western Tasmania.

Within the composite batholiths, the hornblende-biotite granodiorite plutons are generally older than the biotite and garnet-cordierite-biotite granite plutons. This has been substantiated by radiometric dating which has also shown that although there is some overlap in the age of the granitoids between eastern and western Tasmania, the biotite granites of western Tasmania are generally younger than the granitoids in eastern Tasmania (Tables 8.1, 9.19, Figure 10.2).

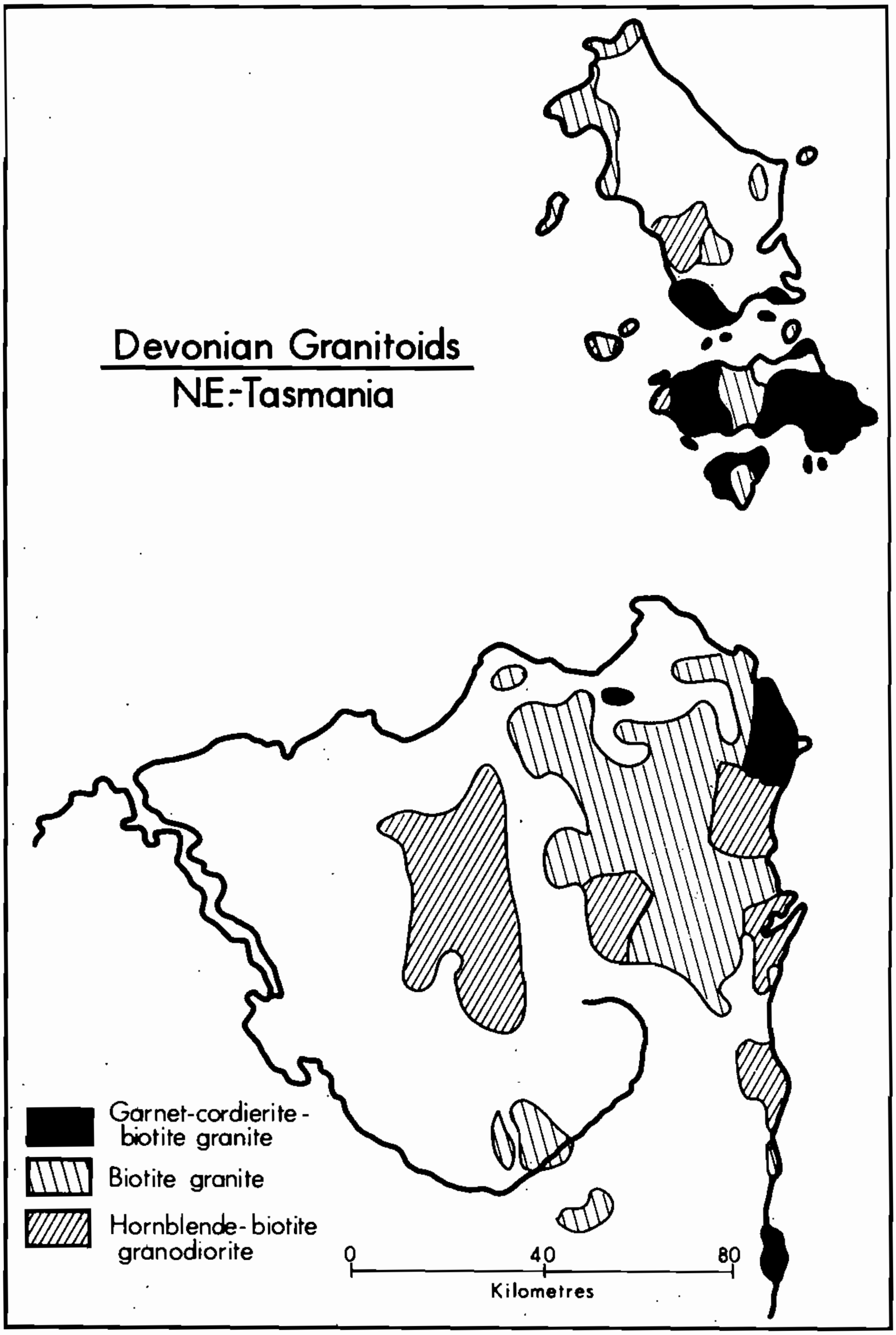

Devonian Granitoids
NE:-Tasmania
Garnet-cordierite-biotite granite
Biotite granite
Hornblende-biotite granodiorite
0
40
80
Kilometres

FIGURE 2.1.

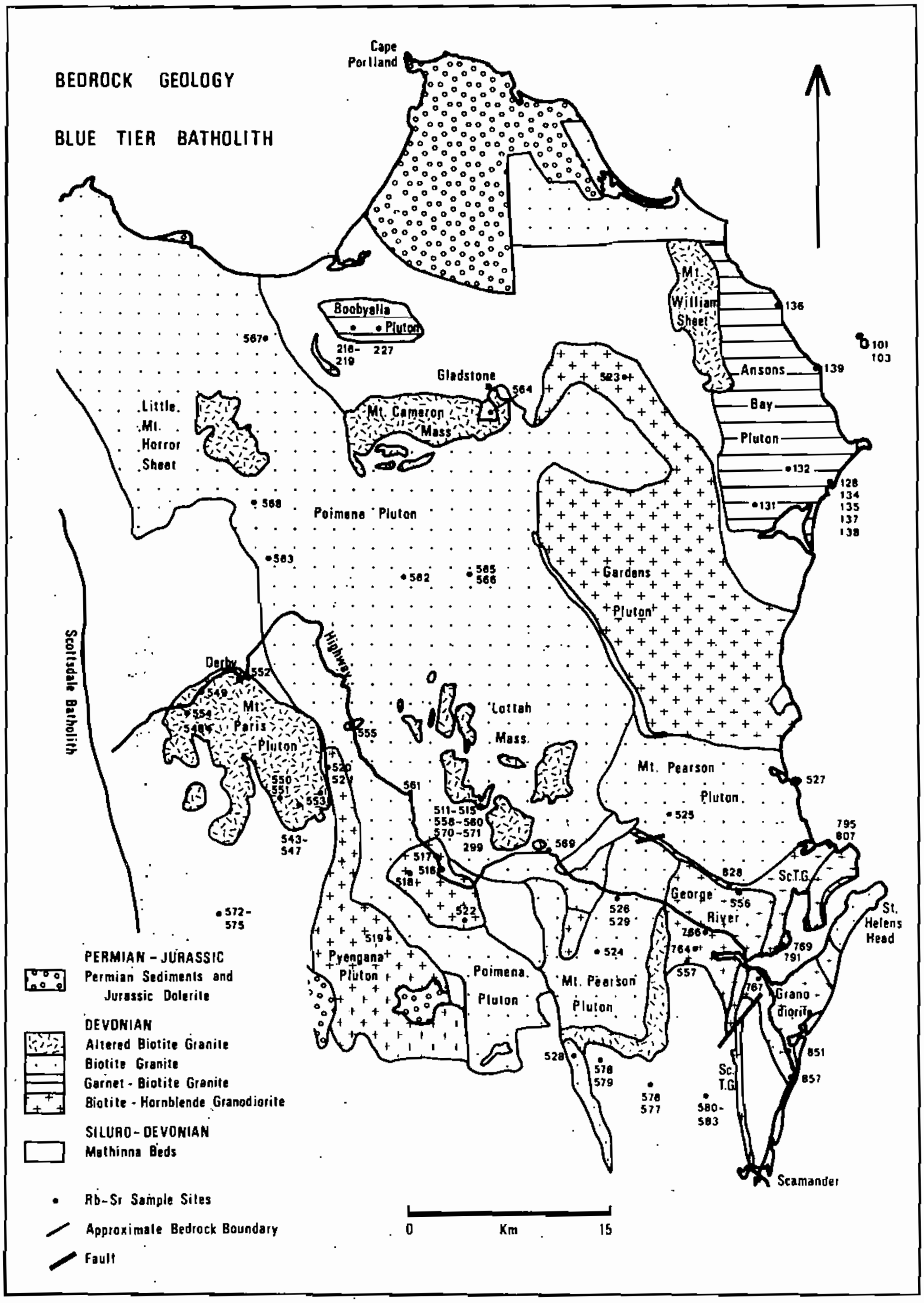


FIGURE 2.2. Bedrock geology of the Blue Tier Batholith. Complete sample numbers are given in Chapter 9.

Field and petrographic characteristics of the three groups of granitoids are compared in Table 2.1. Although there are many similarities between the garnet-cordierite-biotite granites and biotite granites, these groups are considered separately in Chapters 3 and 4 to emphasize the mafic mineral assemblages. There is considerable overlap in the chemical composition between these two groups (section 7.3). The altered biotite granites include plutons with a wide range of alteration features, from pervasively clouded feldspars in otherwise petrographically unaltered biotite granites, to rocks composed of entirely secondary, subsolidus minerals.

2.2 Emplacement of the Tasmanian Granitoids

Roof lifting in a compressional environment and minor marginal deformation and stoping were the main modes of intrusion for the three groups of contact-aureole granitoids. The granitoid plutons are late-tectonic, cutting the major fold trends. Sharp, and in some cases chilled, transgressive contacts between adjacent granitoid plutons and between the plutons and the country rocks suggest high levels of intrusions. These aspects of the emplacement of the Tasmanian granitoid plutons are briefly considered below.

Gee and Groves (1971) and Groves (in press) interpret the environment during intrusion as tensional, based mainly on the evidence for the disruption of the Pyengana Pluton by the intrusion of the Poimena Pluton (Figure 2.2). Most field features, including the disruption of the Pyengana Pluton, are also consistent with intrusion of the granitoid plutons into a region of crustal compression. The relatively long, straight pluton-pluton and pluton-country rock contacts suggest that many plutons were intruded along faults at high levels in the crust. As there is little evidence around most pluton contacts for the shouldering aside of the surrounding rocks and inclusions are not abundant away from pluton margins, the ascending magma or crystal mushes were probably accommodated in the crust by roof lifting. The Scamander Tier Granodiorite is perhaps the best example of a pluton

Table 2.1

CHARACTERISTICS OF TASMANIAN GRANITOIDS

	Garnet-Cordierite Granitoids	Unaltered Biotite Granitoids	Altered Biotite Granitoids	Hornblende Granitoids
Rock Colour & Rock Type	Predominantly grey granites. Two altered plutons.	Grey granites.	Cream to red granites & alkali-feldspar granites.	Grey, mainly granodiorites.
Foliation	Poorly developed cataclastic deformation. K-feldspar megacrysts aligned & segregated.	K-feldspar megacrysts define up to 2 sets of foliations. Strong mafic mineral foliations rarely developed.	K-feldspar phenocrysts and megacrysts commonly aligned.	At least 2 periods of contrasting cataclastic deformation.
Inclusions	Rare, except on contacts with country rocks. Large (20-100m. wide) stoped country rock blocks mainly near contacts.	Rare, except on contacts with country rocks.	Very rare.	Dioritic inclusions widespread. Country rock inclusions common near contacts.
Texture	Porphyritic to equigranular; fine to coarse-grained.	Porphyritic to equigranular; fine to coarse-grained.	Extremely variable within plutons; porphyries and equigranular rocks; fine to medium-grained.	Porphyritic to equigranular; medium to coarse-grained.
Biotite	Red-brown pleochroism, Fe-Al rich.	Red-brown pleochroism, Fe-Al rich.	Pale brown-colourless pleochroism, Fe-Al rich; partially altered and subsolidus origin.	Dark-brown to dark-green pleochroism; relatively Mg-rich.
Plagioclase	Zoned from andesine to oligoclase.	Andesine cores to oligoclase rims.	Acid oligoclase to albite, poorly zoned.	Well developed oscillatory zoning. Labradorite cores to acid oligoclase rims.
K-feldspar	Simply twinned, perthitic, dominantly orthoclase.	Simply twinned, perthitic, dominantly orthoclase	Simply twinned, perthitic, dominantly orthoclase	Simply twinned orthoclase or microcline.
Accessory Minerals	Apatite, zircon, andalusite, tourmaline, Fe-Ti oxides.	Apatite, zircon, Fe-Ti oxides.	Apatite, zircon, Fe-Ti oxides, rare orthite.	Apatite, zircon, sphene, orthite, Fe-Ti oxides.
Secondary Minerals	Pale green biotite after garnet and cordierite; white-mica after feldspars and cordierite; tourmaline after feldspars and garnet.	Fine-grained white-mica after plagioclase; chlorite after biotite. Rare white-mica up to 2 mm. wide after K-feldspar and biotite.	Extensively developed white-mica after feldspars, fine-grained (less than 0.5mm) after plagioclase, up to 5 mm after K-feldspar and biotite. K-feldspar clouded by fluid (?) inclusions. Rare chlorite, topaz, after albite (?). Widespread fluorite and carbonate minerals. Tourmaline is an ubiquitous secondary accessory phase.	Chlorite after biotite and hornblende. White-mica after plagioclase rarely exceeding 0.1mm in grainsize.

forcefully intruded along a possible fault system (Cocker, 1976). Forcible rather than permissive dilation may also be postulated for the intrusion of the Poimena Pluton where it disrupts the Pyengana Pluton.

Evidence for the shouldering aside of country rocks is limited to the marginal deformation around the contacts of the Pyengana (Gee and Groves, 1971 - Figure 1) and George River (Cocker, 1976) Plutons, and the change in regional fold vergence about several plutons in north-eastern Cape Barren Island (Figure E.1). The deflection of regional bedding and fold axes about the margins of these plutons is not of sufficient magnitude to restore the country rock to its pre-intrusion state. Consequently, roof lifting as well as marginal deformation is required to accommodate these plutons in the upper crust. On a smaller scale, structural features both within the hornblende-biotite granodiorites (foliation and flattening of xenoliths) and the country rocks adjacent to the contacts suggest lateral pushing, lifting of roof rocks and forcible dilation of splayed surfaces (Gee and Groves, 1971, 1974; Cocker, 1976).

The low proportion of country rock inclusions in the Tasmanian granitoids, even at these relatively high crustal levels, limits the role of stoping as an emplacement mechanism. The proportion of inclusions probably averages less than 2 percent and rarely exceeds 5 percent within 200-300 m. of the contacts. Included in these estimations are the large (up to 300 $m.^2$) Mathinna Beds blocks which occur along contacts in the Ansons Bay, Key Bay, Kent Bay and Modder River Granites. Stoping, followed by the removal of the low specific gravity stoped blocks to the base of a pluton under the influence of gravity, must be limited, because the dense phase garnet and relatively dense rock type hornblende-biotite diorite have been brought up with the magmas to high crustal levels (section 12.2.3).

White et al. (1974, 1976) have argued that the granitoids of the Lachlan Orogen in New South Wales and Victoria have been emplaced by diapirism and roof lifting. Based on fault and foliation patterns and the shapes of intrusions, White et al. (1974) suggested that the granitoids were intruded into a region with a compressive stress field. Structural data available for the Tasmanian granitoids are consistent with emplacement by roof lifting in a zone of compression, but more detailed field work especially on the fault and foliation patterns in the granitoids and the contact aureoles is necessary. The foliation patterns in the hornblende-biotite granodiorites have been related to intrusive pressures within the plutons (Gee and Groves, 1974). The widespread, K-feldspar megacryst foliations in the biotite granites and the garnet-cordierite-biotite granites were probably formed in response to regional stress fields during the late stages of intrusion, rather than in response to internal intrusive pressures.

CHAPTER 3

GEOLOGY AND PETROGRAPHY OF THE GARNET-CORDIERITE-BIOTITE GRANITOIDS

3.1 Introduction

In the following sections the geology and petrography of the garnet-cordierite-biotite granites are described. Their field and thin-section characteristics imply that the mafic minerals crystallized early from the melt and underwent subsolidus reactions after intrusion. Prior to the present work, many of the 13 garnet-cordierite-biotite granite plutons (Table 3.1) have not been described, including the southern Furneaux Group plutons (Figure E.1) discussed in more detail in Appendix E, and the Bicheno (Figure 3.3) and Maria Island (Figure 1.2) Granites. The three garnet-cordierite-biotite granite plutons which occur in the Blue Tier Batholith (Figures 2.1, 3.1, 3.2) have been briefly described by Gee and Groves (1971) and Groves (in press).

The garnet-bearing aplites and pegmatites are considered in section 3.4, where it is shown that the garnets of these rocks are distinguished by their texture and composition from those of the garnet-cordierite-biotite granitoids.

3.2 Field Characteristics

3.2.1 Contact Metamorphism

The garnet-cordierite-biotite granite plutons of eastern Tasmania intrude the lutites and arenites of the low-grade, regionally metamorphosed Mathinna Beds country rocks (section 10.1), and give rise to narrow (up to 300 m.) contact metamorphic aureoles. The contact metamorphic aureole of the Key Bay Granite on Clarke Island (Figure E.1) is distinguished in the South Head area by a wide aureole (up to 2 km.) and a small contact migmatite outcrop (Plate 1). This unusually wide aureole may also be partly due to an unexposed pluton or the Clarke Island Granite. The hornfels have granoblastic textures and are composed of quartz, K-feldspar, cordierite, biotite, andalusite and muscovite

Table 3.1

GARNET-CORDIERITE-BIOTITE GRANITE PLUTONS

	Pluton	Location	Intrusive Relations	Mafic Minerals
McClenaghan	Mt. Kerford	F.G. Figure E.1	Into M.B. By Hogans Hill Pluton	BT-GT-rare Cord
Reid	Hogans Hill	F.G. Figure E.1	Into Mt. Kerford Pluton	BT-GT
	Key Bay	F.G. Figure E.1	Into M.B.	BT-GT-rare Cord
Reid	Puncheon Point	F.G. Figure E.1	Into M.B.	BT-Cord
Reid	Dover River	F.G. Figure E.1	Into M.B. By Rooks River Pluton	BT-rare Cord
Reid	Clarke Island	F.G. Figure E.1	Into M.B. By Rooks River Pluton	BT-rare GT
Reid	Modder River	F.G. Figure E.1	Into M.B. By Rooks River Pluton	BT-rare Cord and GT
	Kent Bay	F.G. Figure E.1	Into M.B.	BT-rare GT and Cord
	Boobyalla	B.T.B. Figures 2.1,3.1	Into M.B.	BT-GT
	Ansons Bay (composite pluton)	B.T.B. Figures 2.1,3.2	Into M.B. and Musselroe Point Pluton By Mt. William Pluton	BT-GT-rare Cord
	Musselroe Point	B.T.B. Figures 2.1,3.2	By Ansons Bay Pluton	BT-Cord-rare GT
	Bicheno	Separate Body Figure 3.3	Into M.B.	BT-Cord-GT
	Maria Island	Separate Body Figure 1.2	Into M.B.	BT-rare GT and Cord

F.G. Furneaux Group
B.T.B. Blue Tier Batholith
M.B. Mathinna Beds

Into - Intruded into ...
By - Intruded by .....

GT - garnet; BT - biotite; Cord - cordierite (in order of abundance)..

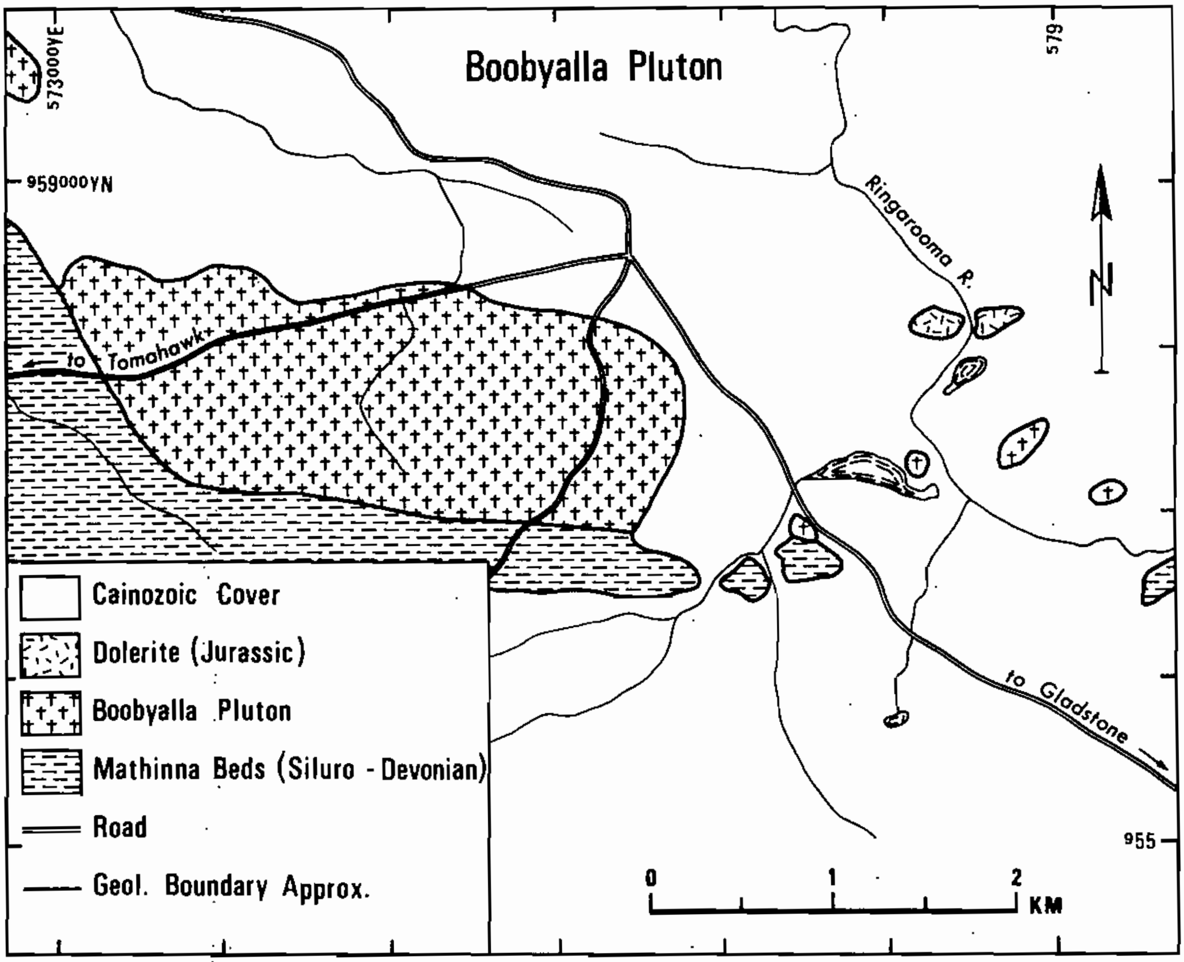

Boobyalla Pluton
573000YE
579
959000YN
955
Ringarooma R.
N
to Tomahawk
to Gladstone
Cainozoic Cover
Dolerite (Jurassic)
Boobyalla Pluton
Mathinna Beds (Siluro - Devonian)
Road
Geol. Boundary Approx.
0
1
2
KM

FIGURE 3.1.

PLATE 1

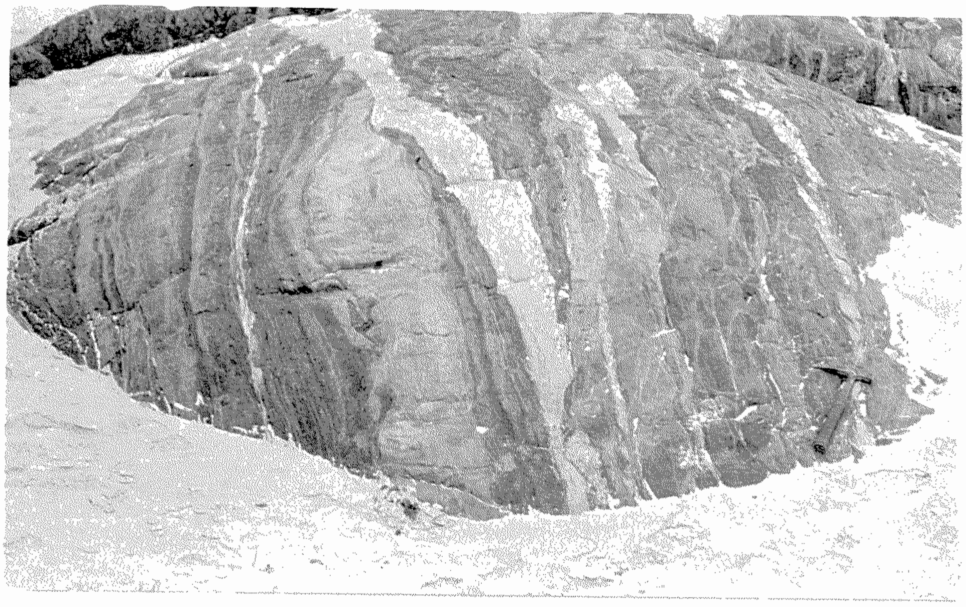
Stromatic, contact migmatite, South Head, Clarke Island (ER/997.058). The felsic layers are boudinaged and the migmatite is transgressed by irregular, younger aplite dykes. Outcrop is 6 m. wide.

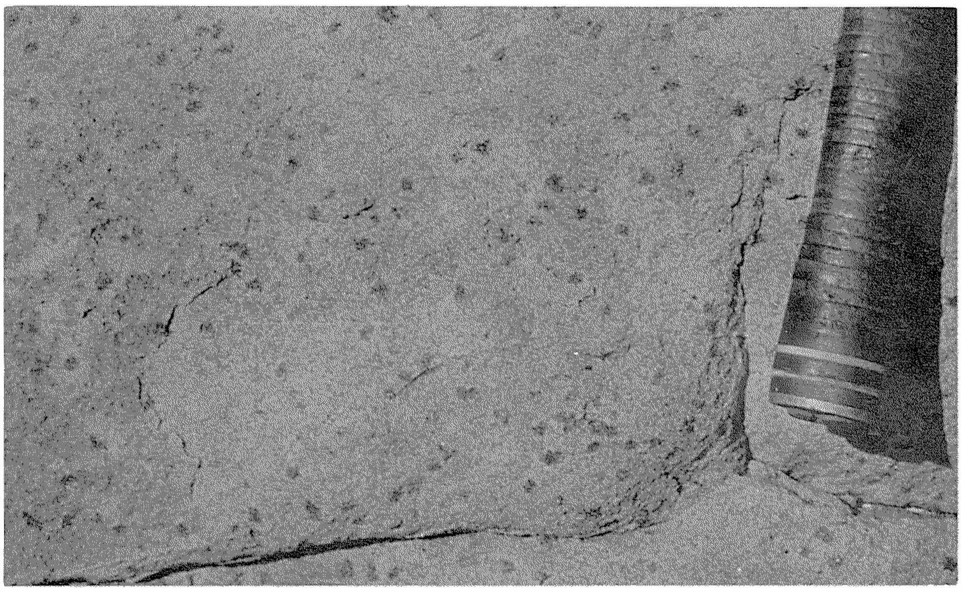
PLATE 2

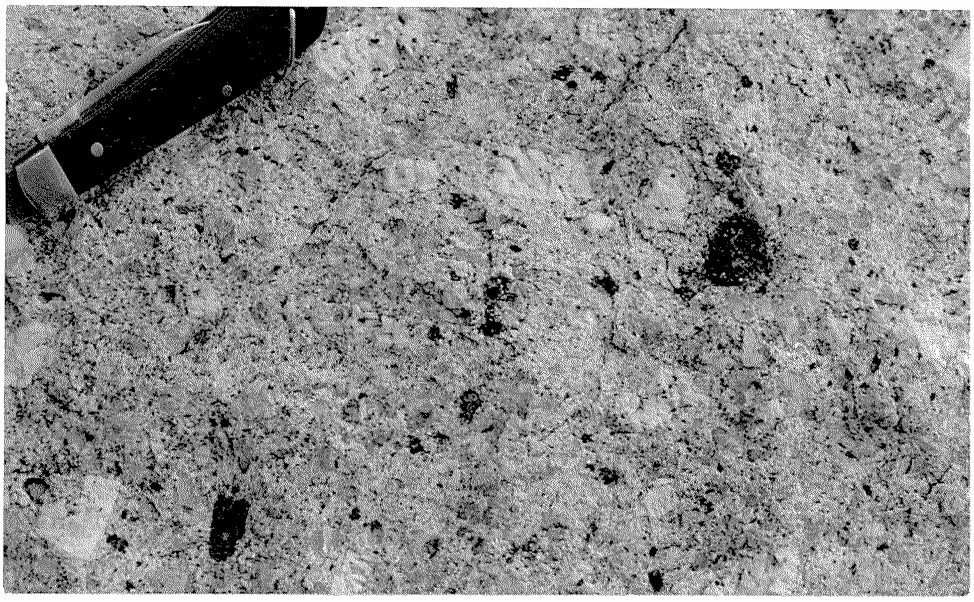
Spotted, cordierite-bearing Musselroe Point Microgranite (69/006.683). The cordierite grains are part of the granular mosaic of the micro-granite or are intergrown with the biotite, quartz and feldspars.

PLATE 3

Garnet (equidimensional) and cordierite (tabular) phenocrysts, in a porphyry, Bicheno Granite (FP/087.629).





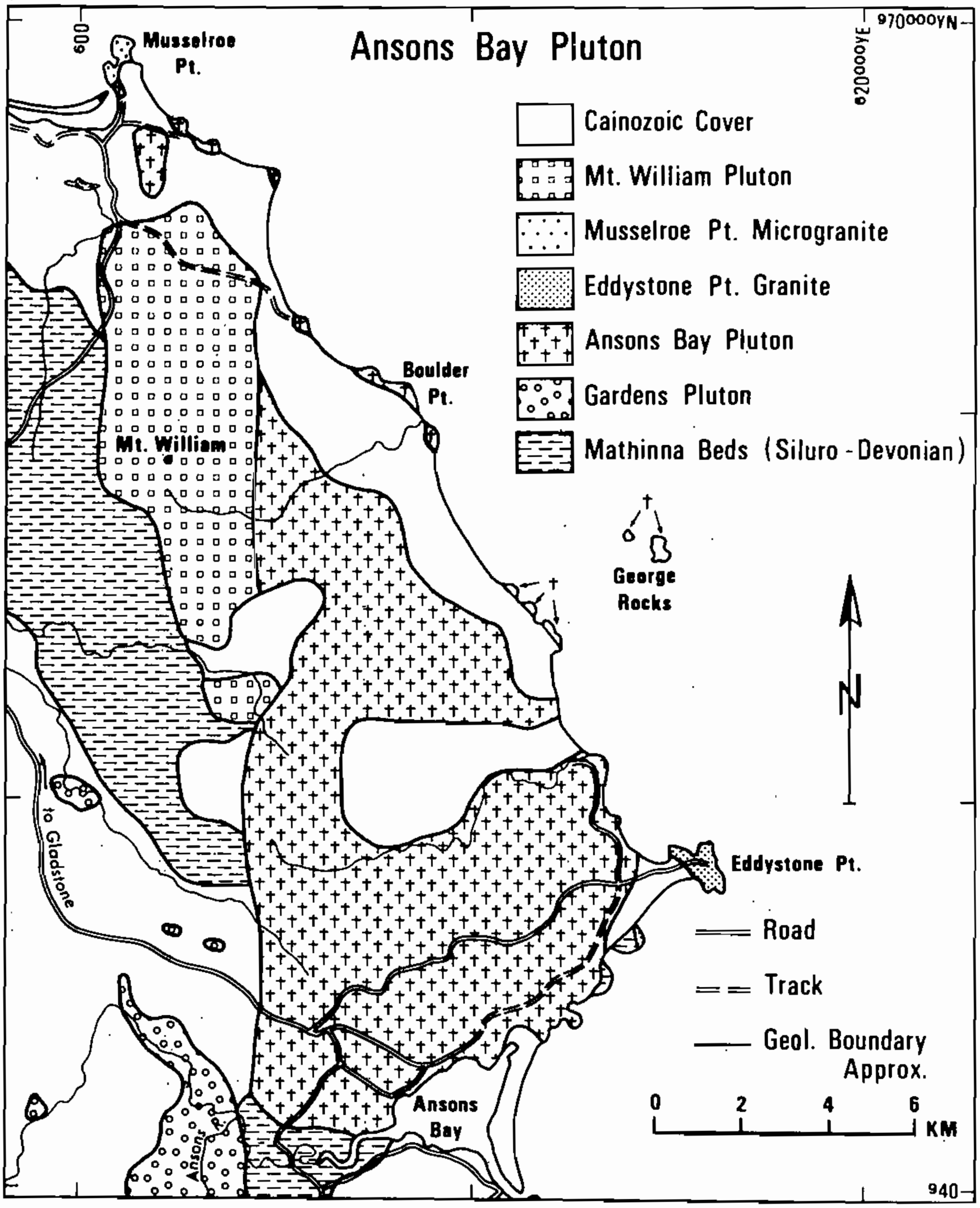


(43301, 43917). In most aureoles in north-eastern Tasmania, the primary metamorphic assemblage has been retrogressed, and former cordierite and andalusite are pseudomorphed by white-mica.

Many of the garnet-cordierite-bearing plutons also intrude other granitoid rocks or are intruded by younger plutons (Table 3.1). The garnet-bearing Hogans Hill Granite has chilled margins against the garnet-bearing Mt. Kerford Granite and intrudes the latter as a dyke complex. Also the cordierite-bearing Musselroe Point Microgranite is intruded by dykes of the garnet-bearing Ansons Bay Pluton.

3.2.2 Textural Variations

The garnet-cordierite-biotite plutons have a range in texture between coarse-grained equigranular rocks and granite porphyries. In some plutons a single textural variant may be dominant, such as the granite porphyries and the porphyritic granites of the Hogans Hill and Boobyalla Plutons, and the medium-grained equigranular granites of the Key Bay and Puncheon Point Plutons. The Ansons Bay and Mt. Kerford Plutons may be subdivided into two fairly distinct areas, although the boundary between the two is gradational or the intrusive relations are complex. In the Ansons Bay Pluton north of Eddystone Point, a coarse-grained equigranular granite is distinguished from a medium-grained, equigranular granite south of Eddystone Point. The field separation is supported by biotite and garnet chemistry (section 6.4) and Sr isotopic analysis (section 9.3.3). On the other hand, there appears to be no compositional data supporting the distinction between the equigranular and porphyry phases of the Mt. Kerford Pluton, in which both rock types intrude each other and occur as inclusions one in the other. The Bicheno Pluton has the most complex range in rock types, with widely varying proportions of phenocrysts (5-80%) and variable grain sizes. Although broad areas such as granite porphyries and equigranular granites can be delineated in the Bicheno Pluton, there are numerous areas where transitional rock types, such as medium-grained groundmass porphyry and K-feldspar megacryst-bearing equigranular granite,



Ansons Bay Pluton
Cainozoic Cover
Mt. William Pluton
Musselroe Pt. Microgranite
Eddystone Pt. Granite
Ansons Bay Pluton
Gardens Pluton
Mathinna Beds (Siluro-Devonian)
Musselroe Pt.
Boulder Pt.
Mt. William
George Rocks
Eddystone Pt.
to Gladstone
Ansons R.
Ansons Bay
N
Road
Track
Geol. Boundary Approx.
0 2 4 6 KM
600
970000YN
620000YE
940

FIGURE 3.2.

complicate the simple two-fold division.* In several plutons the principal textural variation is the proportion of K-feldspar megacrysts. In the Key Bay Granite the variation is extreme, with megacrysts comprising up to 80 percent of the fine- to medium-grained groundmass rocks. In the Modder River, Clarke Island and Kent Bay Plutons, although the proportion of megacrysts varies widely (5 to 20%), the higher megacryst contents are encountered only in fine-grained groundmass rocks. Aplite dykes cut most plutons, but resemble micrograniitic phenocryst-poor phases in the granite porphyries. The Musselroe Point Microgranite is a non-megacrystic microgranite with cordierite 'spots' (Plate 2) composed of intergrown cordierite, feldspars, quartz and biotite. Restricted outcrops of a similar rock type occur in the Mt. Kerford and Dover River Plutons.

3.2.3 Magmatic Flow and Segregation

The distribution of mafic phases within and between plutons is highly variable. Biotite is common to all plutons, varying from approximately 5 percent in the Hogans Hill and Bicheno Granites to 25 percent in the Modder River and Clarke Island Granites. Garnet and cordierite occur as accessory phases rarely exceeding 0.5 percent by volume and commonly less than 0.01 percent. Diligent searching in some of the garnet-cordierite-biotite granite plutons usually results in the discovery of several garnet grains in each large (100 $m.^2$), well exposed, fresh outcrop. However, this is not the case in some of the more biotite-rich plutons such as the Modder River, Clarke Island and Kent Bay Plutons, in which garnet and cordierite grains are rare. The proportion of cordierite phenocrysts in the Bicheno granite porphyries (Plate 3) is of the order of 0.1 percent, in the fine-grained, equigranular Puncheon Point Granite is approximately 0.5 to 1 percent, and in the spotted microgranites is 1 to 5 percent. In other plutons the cordierite or its

*Where most phases occur as both megacrysts and groundmass grains the megacrysts are termed phenocrysts and the rock is termed a porphyry. Distinction between igneous and metasomatic origins for the K-feldspar megacrysts is difficult in most exposures. See later discussion.

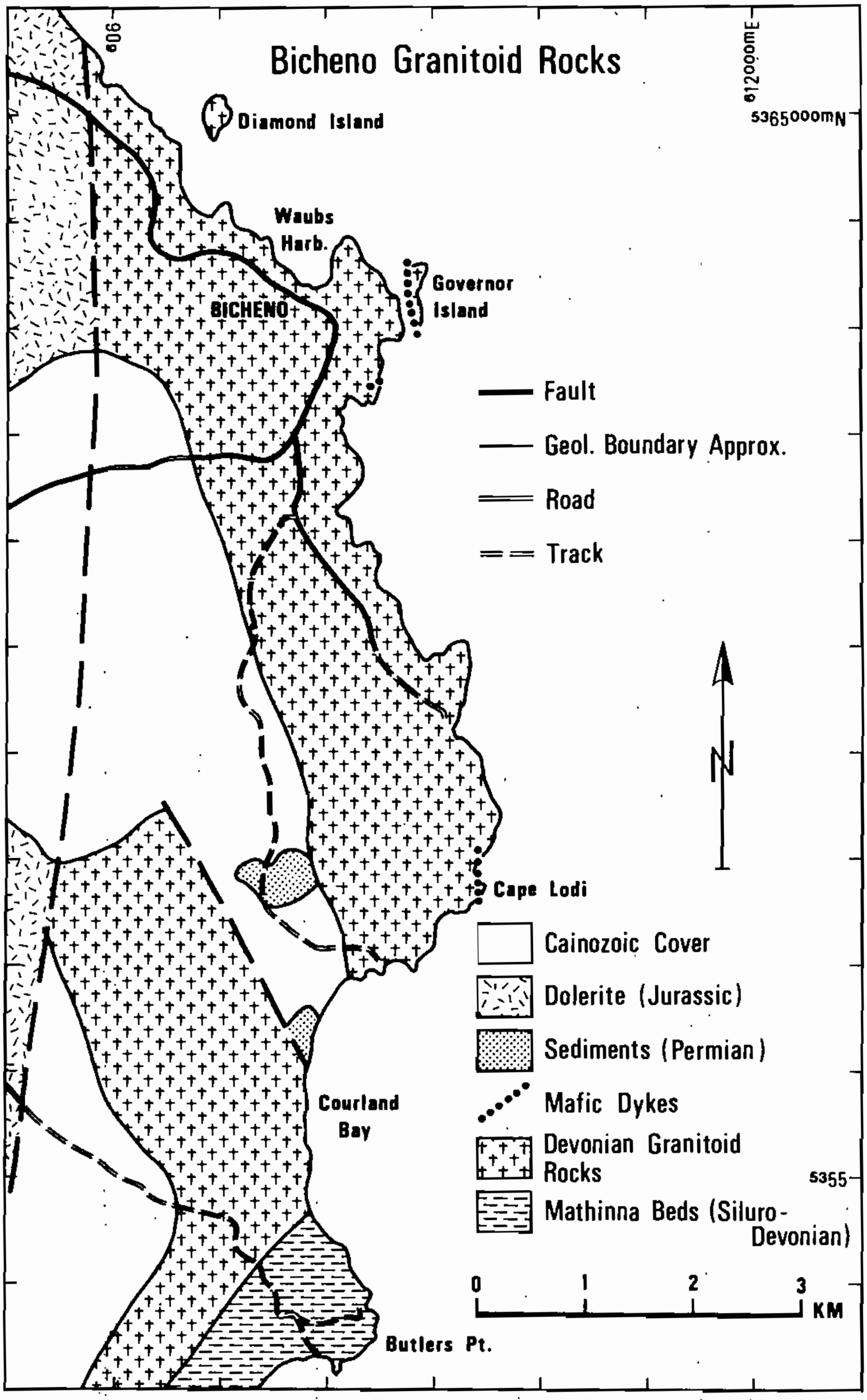

Bicheno Granitoid Rocks
606
612000mE
5365000mN
Diamond Island
Waubs Harb.
Governor Island
BICHENO
Fault
Geol. Boundary Approx.
Road
Track
N
Cape Lodi
Cainozoic Cover
Dolerite (Jurassic)
Sediments (Permian)
Mafic Dykes
Devonian Granitoid Rocks
Mathinna Beds (Siluro-Devonian)
Courland Bay
5355
0 1 2 3 KM
Butlers Pt.

FIGURE 3.3.

pseudomorph are rarely found in hand specimen or thin-section.

Spectacular occurrences of the mafic minerals are found in a continuum of layered to irregular segregations in most plutons. The well-layered complexes (Plates 4, 5) in the Ansons Bay and Mt. Kerford Granites are composed of garnet- and biotite-rich mafic layers grading into normal equigranular granites. The steeply dipping Ansons Bay structure (Plate 4) extends over an area of 50 $m.^2$ and is characterized along strike by rapidly pinching, mafic concentrations. The basal layers carry inclusions from the country rocks. In these two plutons and in the Bicheno Granite, discontinuous spherical to irregularly shaped mafic segregations are concentrated in groups commonly along host rock irregularities (Plate 6). The garnet-rich segregations tend to be spheroidal in shape, the biotite-rich segregations are tabular and the cordierite-rich segregations tend to form intermediate ellipsoidal bodies (Plate 7). Near Key Bay (Figure E.1) in the Key Bay Granite, garnet-biotite spheroids, which range in size from 0.3 to 1 m. in diameter, are closely associated with short biotite layers (less than 1 m. in length) and in this locality appear to be unrelated to changes in the host rock texture. The largest mafic concentrations (0.6 m. wide and 5 m. long) are found along granite porphyry-medium-grained, equigranular granite contacts in the Bicheno Pluton. In several plutons, especially the Ansons Bay and Dover Granites, short (less than 1 m. long), tabular, disoriented biotite layers are common, well in excess of the number of garnet-or cordierite-rich concentrations. In the Ansons Bay Pluton, south of Eddystone Point and near the country rock contact, garnet-rich segregations (Plate 8) are associated with partially assimilated Mathinna Beds inclusions.

The occurrence of K-feldspar megacrysts with the mafic segregations suggests that these grains were concentrated by the same mechanism and were crystallized prior to the aligned K-feldspar megacrysts in the widespread foliations to be discussed below. This is supported by the well developed biotite layering in the biotite-rich Modder River and Clarke Island Granites

PLATE 4

Subparallel, vertical garnet-biotite layers, Georges Rocks, Ansons Bay Pluton (69/150.563).

PLATE 5

Irregular garnet-biotite layer overlain by thin biotite layer in the Mt. Kerford Granite, Kent Bay (FR/127.198). Outcrop is 3 m. wide.

PLATE 6

Garnet-biotite segregation in equigranular granite adjacent to granite porphyry inclusion, Bicheno Granite (FP/085.624).

PLATE 7

Biotite and cordierite-biotite layers intruded by an irregular aplite dyke in a granite porphyry, Bicheno Granite (FP/077.554). The cordierite-bearing layers are lighter in colour (right centre).

PLATE 8

Irregular garnet-biotite segregation associated with partially assimilated Mathinna Beds inclusions in the K-feldspar megacryst-bearing Ansons Bay Granite (69/133.453).

PLATE 9

Biotite layers with parallel and imbricated K-feldspar megacrysts in 'channel-like' structure, Modder River Granite, Clarke Island (ER/964. 161).

in the Furneaux Group. The masses of layered rocks are approximately rectangular in cross-section, up to 50 m. long and 20 m. thick, and are composed of subhorizontal biotite-rich and -poor layers (Plates 9, 40). Tabular K-feldspar megacrysts are parallel to the layering. In Plate 9 the layering is confined to a channel structure on the margin of a larger layered complex and shows imbricated K-feldspar megacrysts and inclusions. If the imbricated form of the K-feldspar megacrysts and inclusions is analagous to imbricated structures in sediments, then the K-feldspar and the inclusions were solid phases being carried in a flowing melt. On Tin Kettle Island (Figure E.1) the biotite layers include rare garnet and cordierite grains.

The north-western outcrops of the Musselroe Point Microgranite are rhythmically layered with typical microgranite layers (up to 2 m. thick) between thin (up to 80 mm. thick) K-feldspar-biotite-garnet layers. The sequence is steeply dipping and is about 50 m. thick. Cordierite has crystallized with other phases in the typical microgranite and not in the thin layers. The layering is interpreted as a flow structure in which the large, early crystallized phases were concentrated, possibly during intrusion.

The mafic mineral and inclusion concentrations in the garnet-cordierite-biotite granites are interpreted as flow structures which concentrated the crystallized phases and inclusions at a relatively early stage in the intrusion history. The disruption of these flow structures by further flow and plastic deformation may have formed the clusters of mafic segregations. This interpretation differs from that of Clarke (1973) who suggests that similar structures in the Kinsman Quartz Monzonite are inclusions. The evidence for flow processes and similar petrographic characteristics of the phases in the segregations and the granites are not consistent with an inclusion origin.

3.2.4 Mafic Inclusions

The mafic inclusion content of the garnet-cordierite-biotite granites is generally low, with the exception of the Modder River, Ansons Bay, Clarke Island and Kent Bay Granites. In these granites, as well as other plutons with lower inclusion contents, the highest proportion of inclusions occurs within 500 m. of the country rock contacts, but rarely exceeds 5 percent by volume. In this zone both well distributed inclusions and inclusion swarms are common. The bulk of the inclusions are biotite-bearing hornfelsed rocks and are comparable to the contact metamorphosed, Mathinna Beds country rocks, although they commonly enclose K-feldspar porphyroblasts which are absent in the metasediments. Adjacent to the contacts the inclusions tend to be angular, but in the swarms and away from the contacts they tend to be rounded. Along contacts of the Key Bay, Modder River, Ansons Bay and Kent Bay Plutons, Mathinna Beds mega-inclusions, up to 300 $m.^2$ but more commonly 100 $m.^2$, are exposed. These are especially common in the Key Bay Granite adjacent to the country rock screen between this pluton and the Modder River Granite. Micro-inclusions, similar to the Mathinna Beds in thin-section, have been found in most plutons, not only adjacent to the contacts. In some of the plutons including the Bicheno, Mt. Kerford and Boobyalla Granites, hand specimen sized inclusions are very rare and no mafic inclusions were found in the Hogans Hill Granite. This is not surprising as the Hogans Hill Granite only intrudes the Mt. Kerford Granite (Figure E.1). In the Mt. Kerford Granite, as well as rare Mathinna Beds inclusions, several biotite gneiss inclusions (43240) and a single biotite-K-feldspar-garnet inclusion (43253) have been found. Field evidence does not suggest that assimilation has played an essential role in the garnet and cordierite crystallization. Garnet or cordierite do not occur in the inclusions (except 43253) and are rarely found adjacent to the inclusion margins (43101, 43118).

3.2.5 Post-Solidification Deformation

Most of the garnet-cordierite-biotite granite plutons have variably developed K-feldspar megacryst foliations. The foliation is prominent in some exposures such as the megacryst-rich (up to 80% megacrysts) Key Bay Granite on Cape Barren Island, but more commonly the foliation is seen as relatively rare, oriented megacrysts (less than 5%). In many plutons the principal strike of the foliation is approximately north-south suggesting an overall regional control for north-eastern Tasmania. These characteristics, and the growth of megacrysts across rock type boundaries in the biotite granites at Royal George (Beattie, 1967), suggest that the K-feldspar megacrysts defining the foliation have grown as porphyroblasts. Berger and Pitcher (1970) and Oen (1960, 1970) suggest that K-feldspar foliations reflect imposed stress fields during the later stages of crystallization and intrusion of granitoid plutons. Detailed structural analysis of critical areas may help distinguish between K-feldspar as an early phase, segregated with the mafic minerals, and as a later subsolidus crystallization product.

The weak cataclastic foliation, evident in some areas of the Modder River, Clarke Island and Kent Bay Plutons, is defined by the alignment of biotite and rarely the felsic minerals. This foliation is similar to the first period of cataclastic foliation in the granodiorites (section 5.2).

3.2.6 Alteration

The Hogans Hill, Bicheno and Maria Island Granites are partly characterized by a variably developed, pervasive alteration giving rise to pink coloured K-feldspar. The alteration is mildly developed throughout the Hogans Hill Granite, but in the other two masses the alteration is closely related to faults and joints. The fractures appear to have been the source for the hydrothermal fluid, but some of the fluid may have been derived from the immediate magma, as rare miarolitic cavities occur in the Bicheno Granite. Little of the garnet and almost none of the cordierite survived the alteration, and the white-mica content of the granites increased greatly.

3.3 Petrography

3.3.1 Introduction

Below, the thin-section characteristics of the textures and the minerals in the garnet-cordierite-biotite granites are considered. Zircon, apatite, ilmenite, garnet, cordierite, red coloured biotite, plagioclase, quartz, K-feldspar and possibly andalusite are supersolidus phases, whereas tourmaline, white-mica, pale green biotite, chlorite, topaz and andalusite are near-solidus and subsolidus phases. Primary and secondary biotite can be clearly distinguished in thin-section, but similar relationships suspected for the K-feldspar from the field distributions could not be substantiated. The paragenesis has been established using inclusion relationships and reaction textures.

The predominant textures in these rocks are hypidiomorphic-granular to allotriomorphic-granular, with the latter form especially common in the groundmass of the granite porphyries. In the medium- to coarse-grained rocks the mafic minerals and plagioclase, and quartz adjacent to K-feldspar in the Mt. Kerford and Dover River Granites, tend to be subhedral phases. The phenocrysts and megacrysts also tend to be euhedral to subhedral phases with the feldspars commonly enclosing groundmass grains. Embayed glomerocrysts of quartz are common in the porphyries whereas feldspar glomerocrysts are rare. Most grain boundaries are straight with relatively little evidence of strong adjustment or deformation. In all plutons the quartz displays varying degrees of undulose extinction and in many samples quartz-quartz boundaries are sutured. Kinked biotites are widely distributed in some areas of the Modder River, Clarke Island and Kent Bay Plutons. Dislocated plagioclase twinning and subgrain albite aggregates are not common in these rocks.

3.3.2 Garnet

Euhedral to anhedral garnets occur as an accessory phase in medium- to coarse-grained equigranular rocks, as accessory phenocrysts in granite porphyries and as a major phase (up to 70%) in garnet-biotite concentrations. The garnets range in diameter from 3 to 15 mm. and those grains which have not been largely replaced by secondary biotite have a grain size comparable to the surrounding granular phases or phenocrysts. The garnets in equigranular and porphyry variants within the same pluton have similar sizes. In the plutons with prominent garnet populations, such as the Ansons Bay, Mt. Kerford, Boobyalla and Bicheno Granites, the average size of euhedral garnets ranges from 5 to 10 mm. Dodecahedra (Plate 10) occur in all the plutons except the Bicheno and Maria Island Granites in which the outlines of the original grains are commonly preserved by secondary biotite after the garnet (Plate 3)(43163, 43175). Anhedral garnets have several forms. They occur as remnants within a mass of pale green, secondary biotite (Plate 22) (43182, 43151), as grains enclosed by red-brown biotite (Plate 18) (43124, 43126, 43221), and as remnants enclosed by plagioclase (Plate 17) (43218, 43265, 43276, 43190). Rarely, the garnet appears to be intergrown with quartz (Plate 19) (43199, 43200) and never with feldspars, In both the porphyries and the equigranular rocks, the garnets may be surrounded by red-brown biotite, suggesting synneusis attachment.

The garnets enclose a variety of phases including, in approximate order of abundance, red-brown biotite, quartz, apatite, ilmenite, zircon, rutile, pyrrhotite and possibly sillimanite. Zoning of inclusions in the garnet occurs in sample 43252 (Plate 10) where a zone of quartz and biotite and a zone of apatite needles (Plates 11, 12) mimic the euhedral margins. Feldspars do not occur as inclusions in the garnets. The ilmenite, zircon and one group of apatite grains rarely exceed 0.2 mm. in length. The other group of apatite grains, which themselves include zircon, are included in the garnet or attached to the surface of the garnet (Plate 14), and are 2 to 4 mm. in length. In many garnets the small inclusions are irregularly distributed as groups of three to four attached grains. The sparse distribution of zircon grains within the garnets (Plate 13) is in contrast to the number of pleochroic haloes found in the biotite replacing the garnet (Plate 22). The radioactive source for the pleochroic haloes in the secondary biotite includes both zircon and apatite grains. Sillimanite was tenatively identified in three garnets from the Tasmanian granites (43202, 43204, 43225), and also in sample 43284 from the Rakeahua Granite, New Zealand (Appendix F), where the included needles appear to have exsolved from the garnet (Plate 15). Although quartz inclusions occur in

PLATE 10

Garnet dodecahedron with a zone of quartz and biotite inclusions parallel to euhedral margins.

43252 Partially crossed nicols X13

PLATE 11

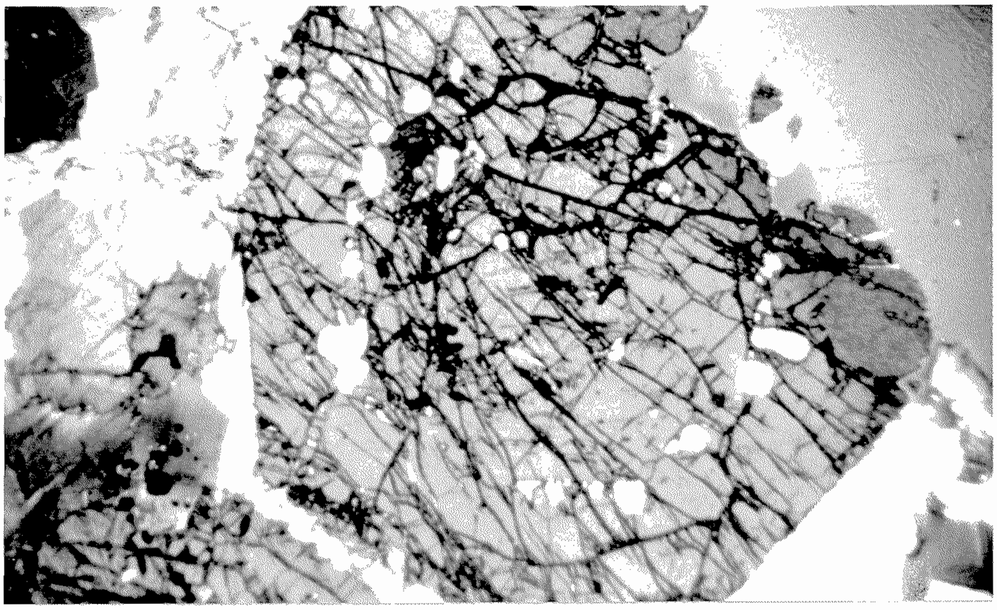
Euhedral garnet with zones of quartz and apatite (between garnet margin and quartz inclusion zone) inclusions which are parallel to the margin of the garnet. Also, isolated apatite needles throughout the field of view tend to be parallel to the garnet margins.

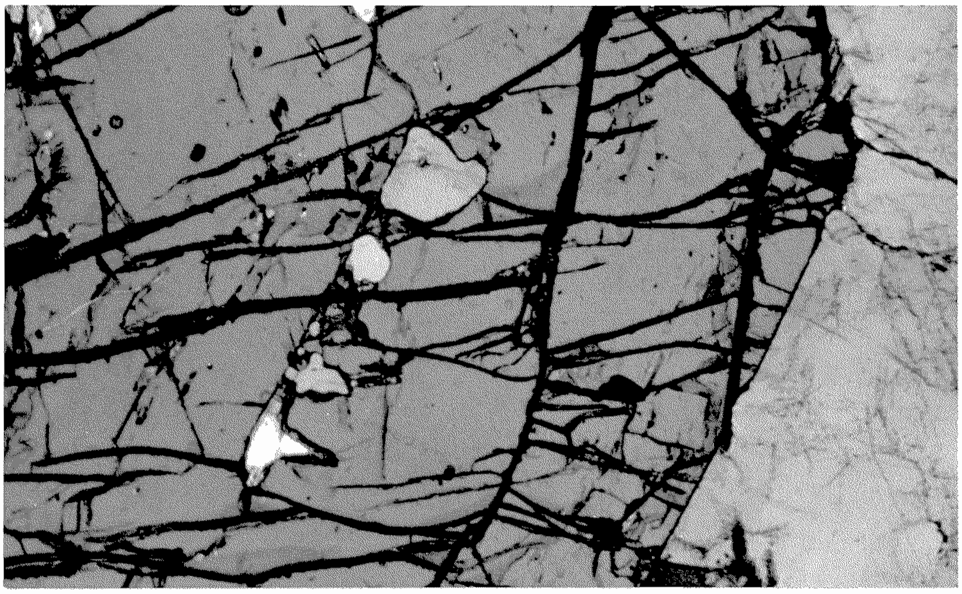
43252 Partially crossed nicols X38

PLATE 12

Sub-parallel apatite needles from inclusion zone near margin of euhedral garnet shown in Plate 11.

43252 Plane polarized light X211





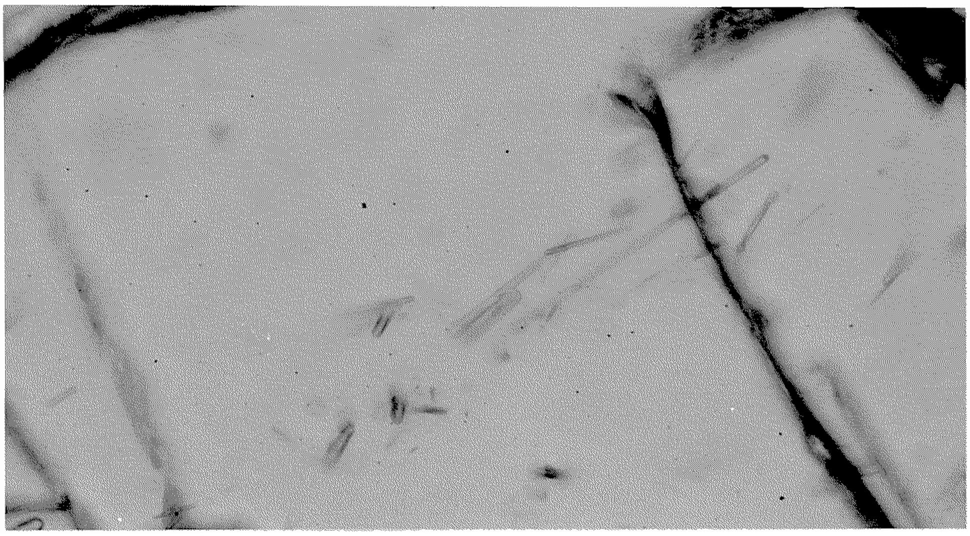


PLATE 13

Zircon with radiation haloe in garnet.

43182 Plane polarized light X232

PLATE 14

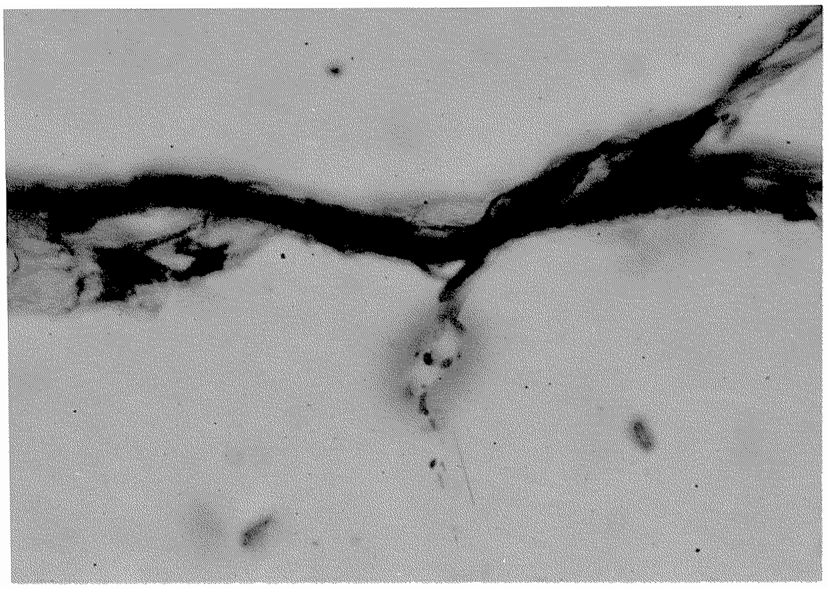
Subhedral apatite enclosed within garnet and adjacent biotite. A second relatively large apatite grain is included in the garnet. Zircon subhedra occur in the apatite, garnet and biotite.

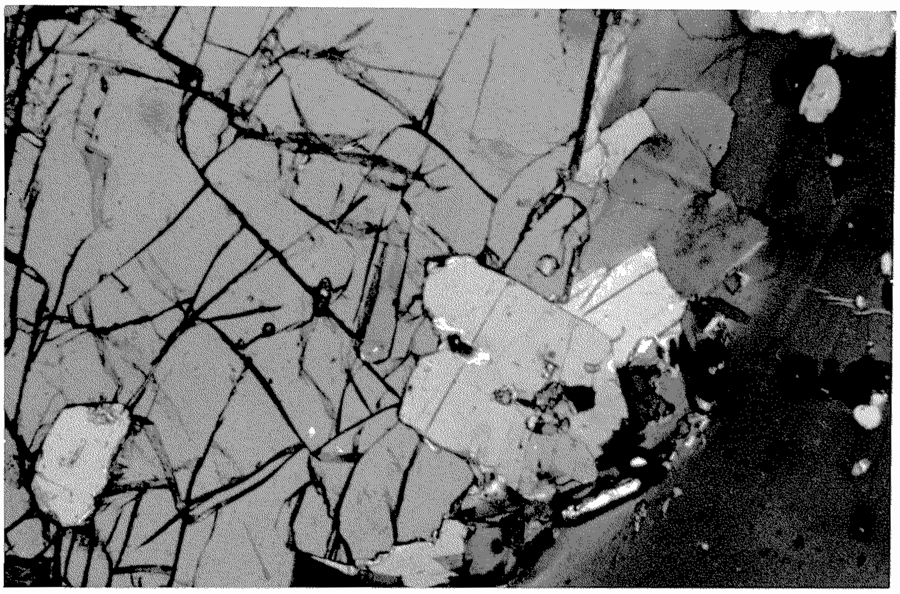
43252 Plane polarized light X38

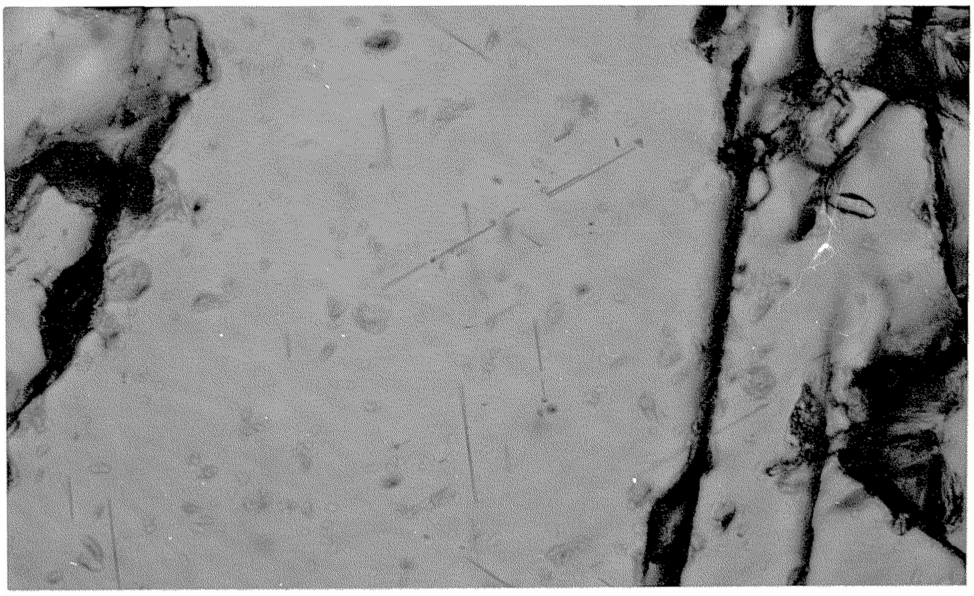
PLATE 15

Sillimanite (?) exsolved from garnet.

43284 Plane polarized light X271







garnets from the Tasmanian granites, they are not as common as those in similar garnets in the Rakeahua Granite (Plate 16). A single rutile and several pyrrhotite inclusions have been identified (electron microprobe) in garnets from the Tasmanian granites. The garnet inclusion relations are common to all the plutons, both in those where garnet is abundant and in those with rare garnet grains enclosed in other phases (Plate 17).

Replacement of garnet by pale coloured biotite is widespread although variably developed within and between plutons. In the Bicheno, Maria Island and Hogans Hill Granites which have been pervasively altered, the garnets are extensively replaced (Plate 22). Chlorite (43184), tourmaline (43102, 43105) and quartz (Plate 19) (43271, 43199) replace garnet along cracks and grain margins in the same pattern as the secondary biotite. The subsolidus garnet replacement is distinguished by pale green (maximum absorption colour) biotite and in critical sections an association between myrmekite in K-feldspar and the pale coloured biotite (Plates 20, 21). In Plate 20 pale coloured biotite extends from a crack in the garnet,across a euhedral garnet-K-feldspar boundary, into a group of myrmekite grains in the perthitic K-feldspar. Intergrown with the biotite and extending along the margin of the garnet and K-feldspar is fine-grained white-mica. This association is well displayed in Plate 21 where a large white-mica grain partially replaces a K-feldspar grain which is largely replaced by myrmekite. If the myrmekite and perthite are accepted as exsolution features of the K-feldspar in these relatively undeformed, contact-aureole granitoids (Phillips, 1964, 1974), then the pale coloured biotite is also subsolidus in origin as it replaces the myrmekite. The replacement of the garnet, along cracks, by tourmaline and quartz (Plate 19) is also thought to occur below the solidus, as in both cases some of the cracks are partially filled with biotite. In several thin-sections the red-brown biotite attached to the margins of the garnets gradually changes in colour, merging with the biotite replacing garnet along cracks (Plate 30). This texture suggests that there may be an overlap in time between the development of the primary and secondary biotite. The rare

PLATE 16

Unoriented quartz inclusions in garnet.

43285 Plane polarized light X87

PLATE 17

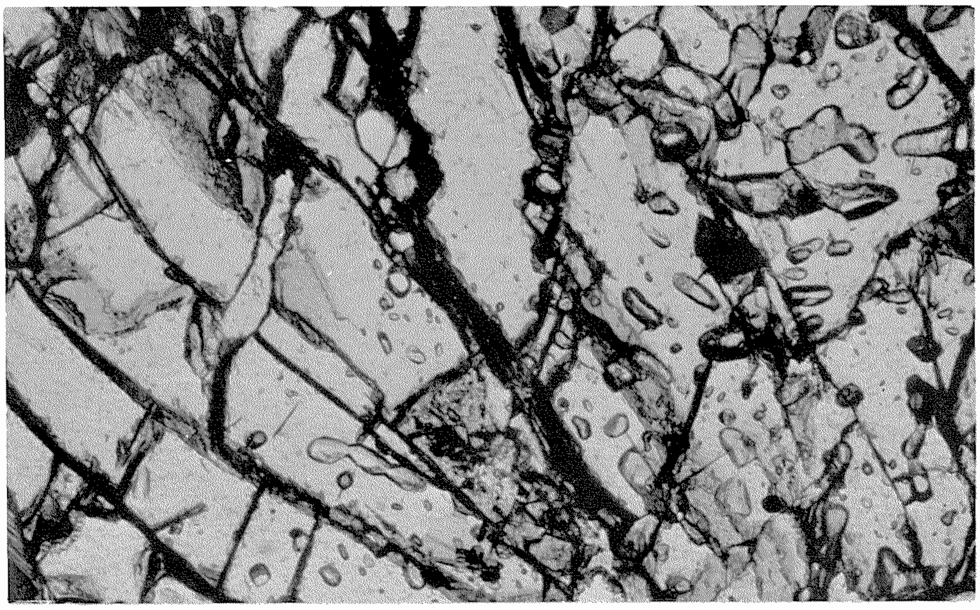
Anhedral garnet included in plagioclase and partially replaced by biotite.

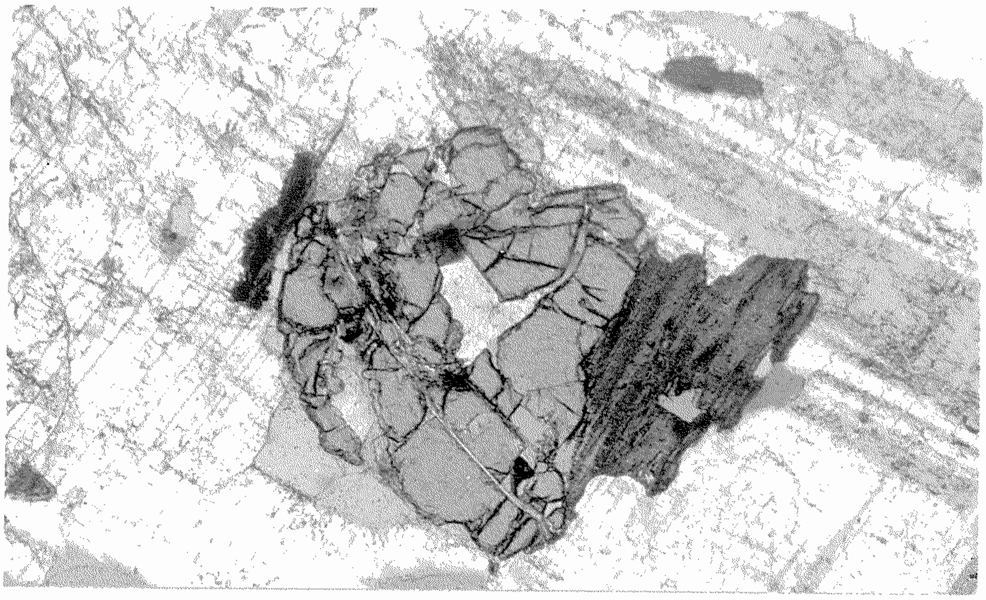
43279 Crossed nicols X46

PLATE 18

Anhedral garnet grains included in biotite and quartz.

43126 Plane polarized light X15.5





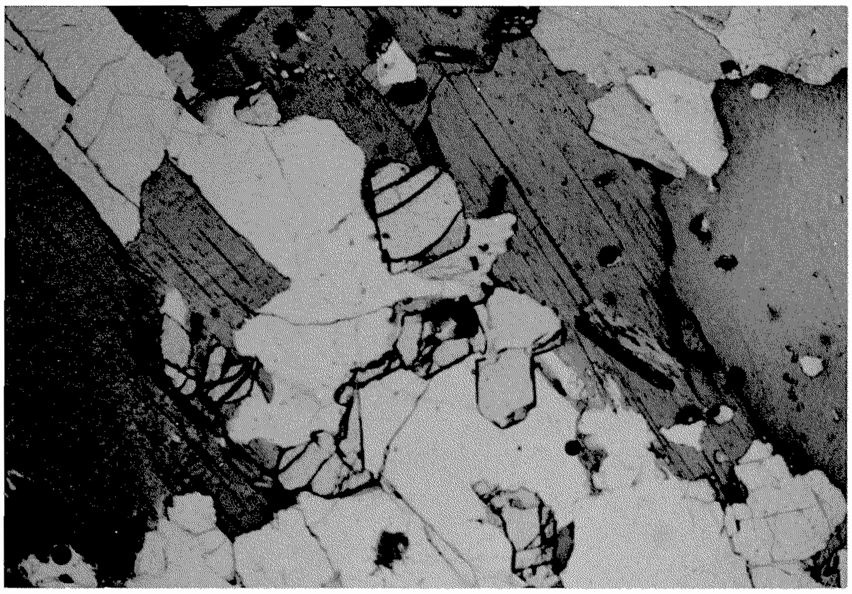


PLATE 19

The prominent crack in the garnet is replaced by quartz and to a lesser extent biotite. The quartz in the crack is in optical continuity with the quartz grain (top) which has replaced an undetermined proportion of the garnet.

43199 Partially crossed nicols X15.5

PLATE 20

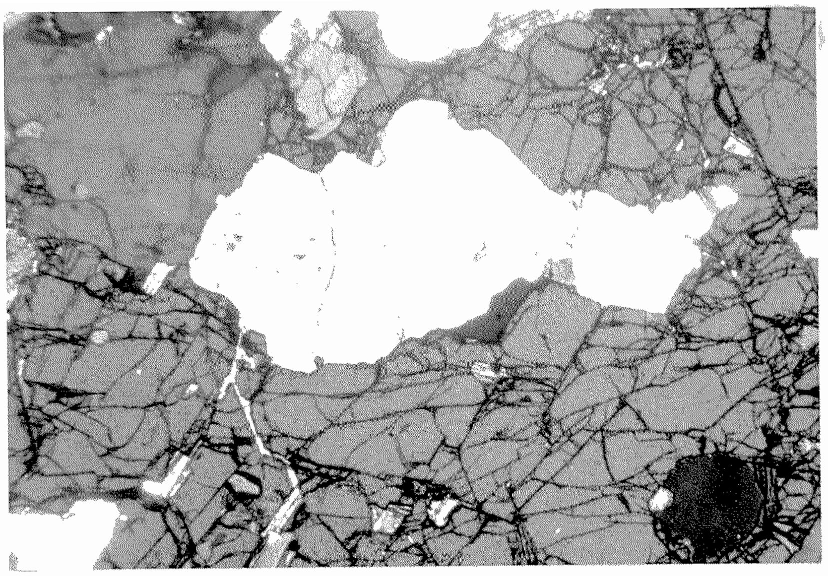
Myrmekite in perthitic K-feldspar adjacent to an euhedral garnet margin and centred on secondary biotite extending from the garnet. Secondary biotite replacing garnet in cracks commonly extends from the garnet grains up to 1 mm. into surrounding feldspars and quartz.

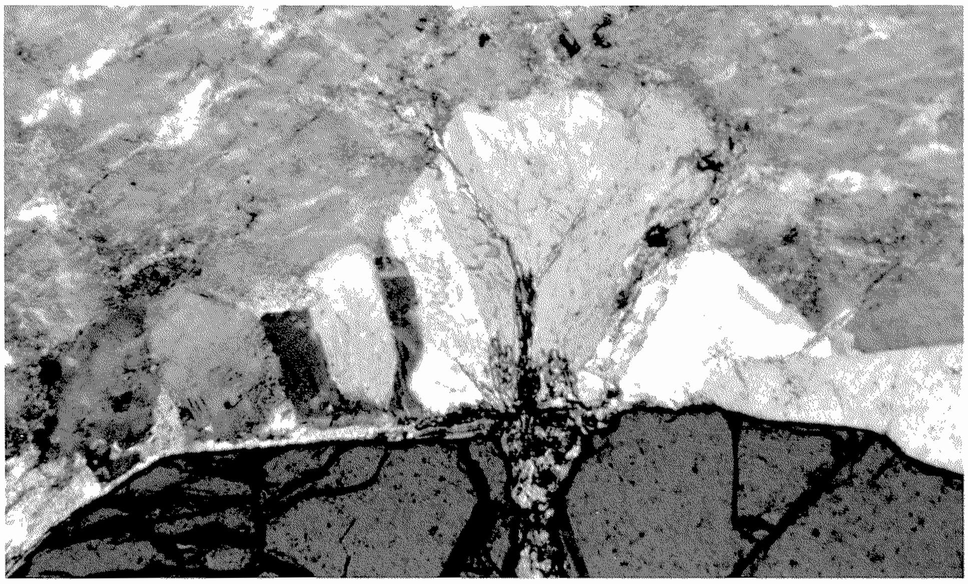
43241 Partially crossed nicols X15.5

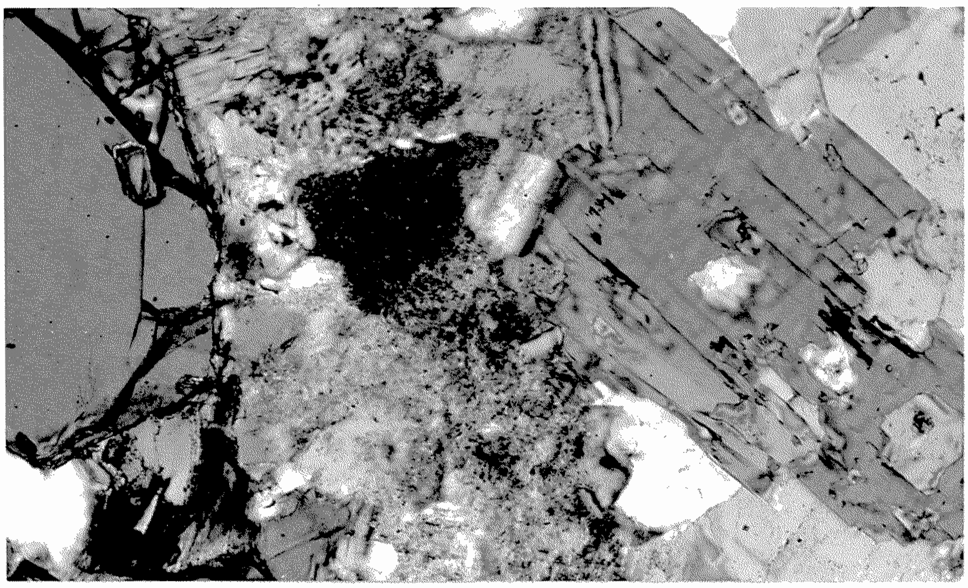
PLATE 21

K-feldspar partially replaced by myrmekite and white-mica adjacent to euhedral garnet.

43133 Partially crossed nicols X121







replacement of garnet and biotite by an intergrowth of andalusite and albite (Plate 23) is another, probably subsolidus, reaction texture.

Based on the lack of pale coloured biotite and on intense resorption zoning near the garnet margins (section 6.5), anhedral garnet which is partly enclosed by red-brown biotite (Plate 18) is thought to have been replaced by the biotite at temperatures above the solidus. This garnet replacement is widespread, but not as common as the subsolidus biotite replacement.

3.3.3 Cordierite

The cordierite in the aluminous plutons has a range of textural forms similar to those of the garnet, and is also intergrown with the felsic minerals and biotite in the Musselroe Point Microgranite. It is most prominent in the Bicheno Granites as euhedral phenocrysts (Plates 3, 24, 25), as an accessory phase in the fine-grained, equigranular Puncheon Point Granite, and as a major component in cordierite-biotite segregations. In the Ansons Bay Pluton six thin-sections contain pseudomorphed cordierite including one sample with remnants of the unaltered mineral (43122). The Dover River, Key Bay, Mt. Kerford, Modder River and Kent Bay Plutons carry pseudomorphed cordierite although only several grains have been found in each pluton.

In the Bicheno Granite only three samples with unaltered cordierite were found (43178, 43161, 43185). The characteristics of the primary mineral are shown by a longitudinal section of a pseudohexagonal crystal in sample 43178 (Plate 24). The cordierite has a simple trilling pattern, encloses minute apatite and zircon grains which are aligned parallel to the long axis of the grain, and is altered from the margin inwards. Unaltered cordierite remnants occur in only two samples (43122, 43202) from other plutons, and in one case the pseudomorphed grains appear to enclose or to be intergrown with red-brown biotite (Plate 27). In the Musselroe Point Microgranite, and in areally restricted microgranites in the Mt. Kerford and Dover River Granites, the cordierite occurs as part of a granular mosaic or is partially intergrown with biotite and the felsic phases.

PLATE 22

Secondary pale coloured biotite replacing garnet along margins and cracks. The pleochroic haloes in the secondary biotite are centred on zircon and apatite grains.

43151 Plane polarized light X38

PLATE 23

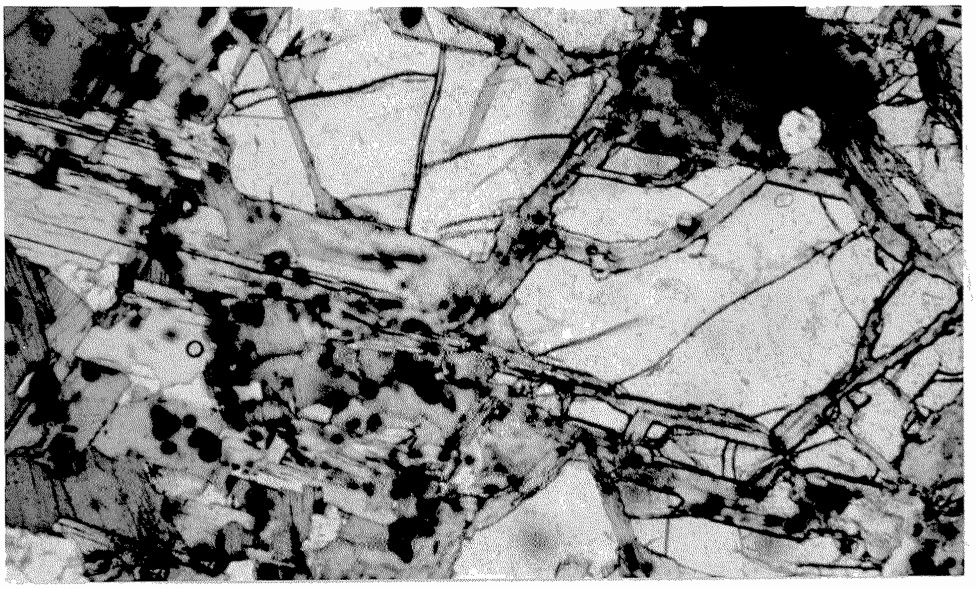
Andalusite-albite intergrowth after garnet and biotite. Both red-brown and colourless biotites appear to be involved in the reaction.

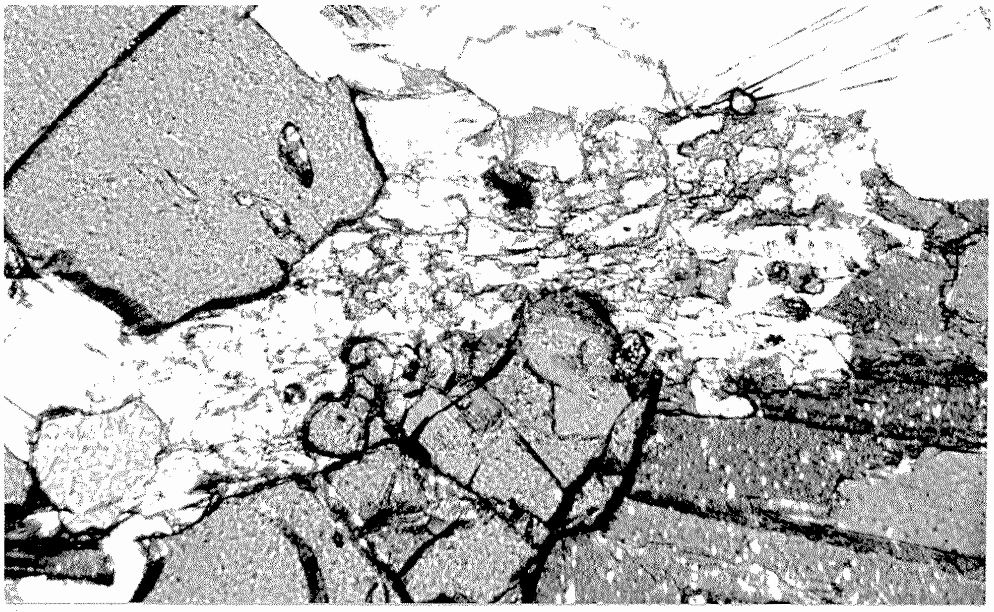
43106 Partially crossed nicols X95

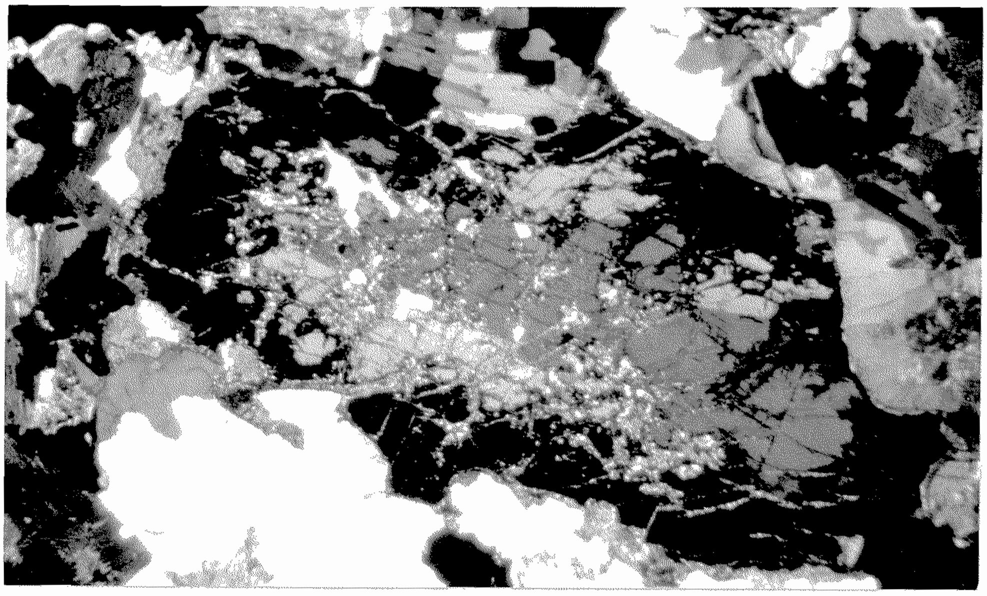
PLATE 24

Longitudinal section through cyclically twinned, subhedral cordierite crystal. The isotropic margin is composed of amorphous replacement compounds and sericite replaces the cordierite along cracks in the interior of the grain. The prominent white inclusions in the cordierite are quartz grains.

43178 Crossed nicols X11







The widespread alteration, which has destroyed most of the primary features of the cordierite, takes varied forms. The main phases which replace cordierite are a pale, sea-green coloured biotite and white-mica and a colourless to red isotropic, amorphous compound. The character of the alteration varies between plutons. In the Bicheno and Ansons Bay Granites the three secondary phases are common, although their proportion varies from grain to grain, with the amorphous phase being prominent (Plates 24, 25, 27). In the Puncheon Point, Kent Bay and Dover River Granites, the sea-green biotite and white-mica are intergrown and replace the bulk of the cordierite (Plates 26, 29). The mica intergrowth is distinctive in these plutons and is readily distinguished from the primary (?) red biotite-white-mica intergrowth (Plate 34) in the Dover Granite. In many cases the alteration follows the 001 planes in the original grain with mica cleavage or dehydration cracks in this plane (Plate 25). The micas replace both the cordierite and the amorphous compound. The cordierite is also replaced by andalusite in some samples (Plate 28). These replacement textures of cordierite are comparable to those found in metamorphic rocks (Schreyer and Yoder, 1961).

3.3.4 Biotite

Biotite in most of the garnet-cordierite-biotite granites is modally in excess of the other mafic phases, ranging from 5 to 25 percent. Biotite may comprise up to 70 percent of mineral segregations where it is petrographically similar to dispersed biotite in the host granites. Various textural forms of biotite have been distinguished:

1. Red-brown subhedral booklets, commonly as clusters in the fine- to medium-grained equigranular granites.

2. Red-brown subhedral booklets as phenocrysts or clusters of phenocrysts in porphyries (clusters up to 20 mm. long). The groundmass biotite is anhedral.

3. Red-brown biotite clustered around garnet phenocrysts and microinclusions.

PLATE 25

Cordierite pseudomorphed by biotite, white-mica and amorphous compounds. The (001) parting is accentuated by mica cleavage and dehydration cracks in the amorphous compounds. The high relief mineral (centre top) is andalusite replacing cordierite (see Plate 28).

43161 Partially crossed nicols X15.5

PLATE 26

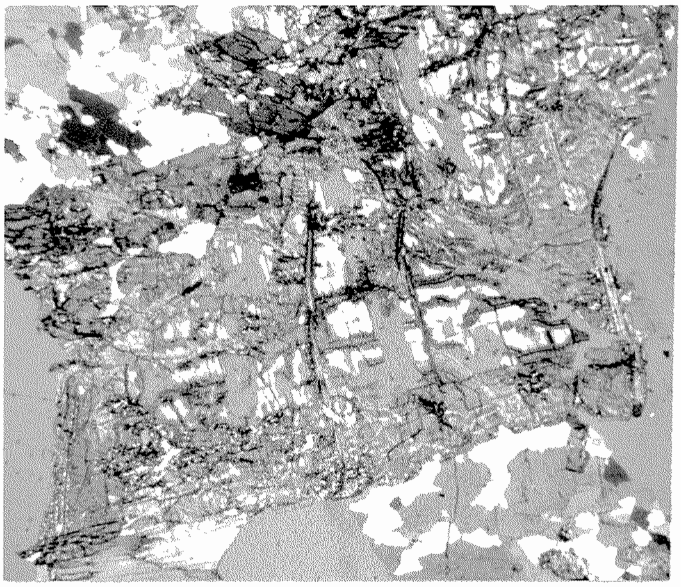
Subhedral cordierite pseudomorphed by intergrown white-mica and pale coloured biotite.

43888 Crossed nicols X15.5

PLATE 27

Cordierite pseudomorphed by amorphous compounds with gel-like structure. The isotropic high relief grain is garnet which appears to be anhedral against the cordierite. The cordierite encloses primary biotite grains.

43122 Crossed nicols X38



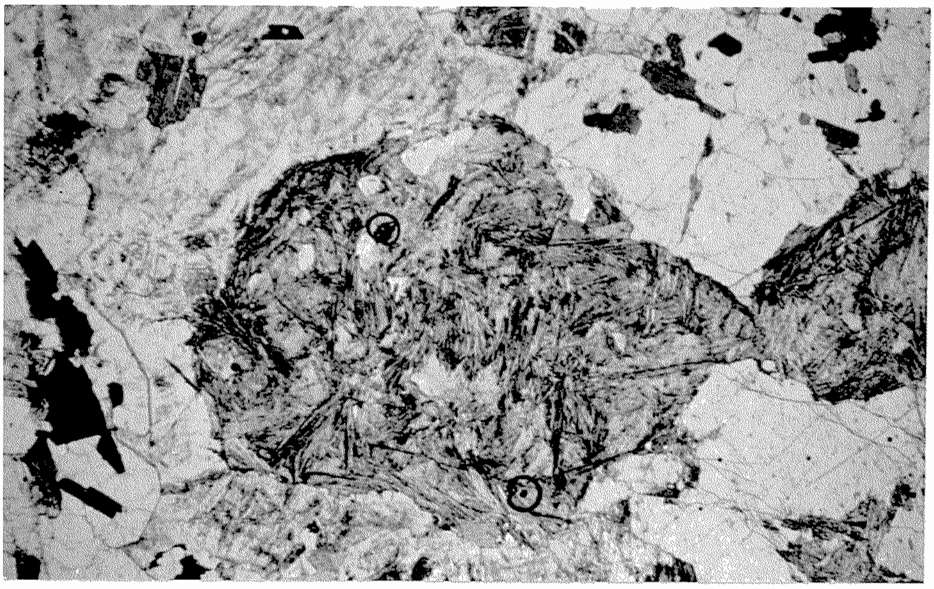


PLATE 28

Cordierite replaced by amorphous compounds, white-mica and andalusite.

43161	Crossed nicols	X38

PLATE 29

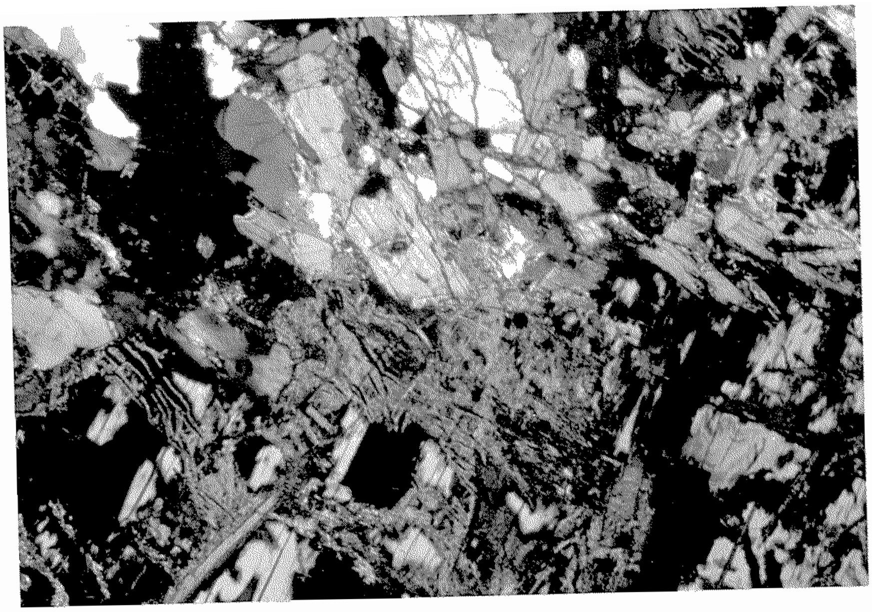
Cordierite replaced by amorphous compounds with dehydration cracks and intergrown white-mica and pale biotite. Possibly the cordierite was replaced by the amorphous compounds which were in turn replaced by the mica intergrowth. The intergrowth, comparable with that found in Plate 26, is composed of wedge-shaped mica individuals.

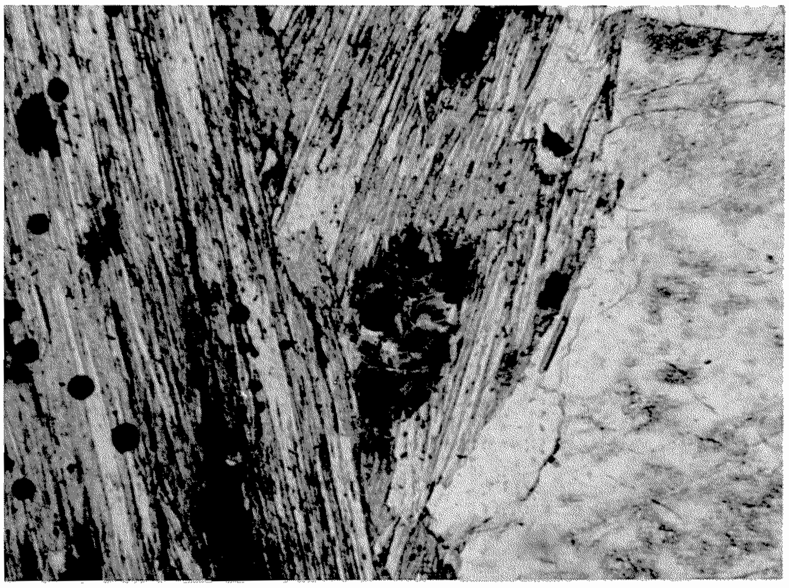
43871	Plane polarized light	X95

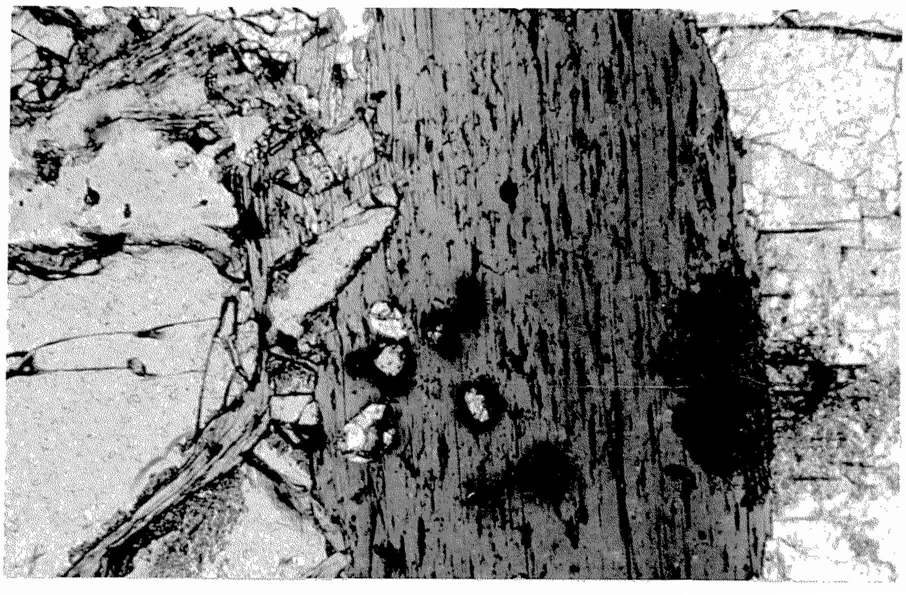
PLATE 30

Biotite booklet adjacent to anhedral garnet margin. The biotite colour, which reflects its composition, changes from red-brown away from the garnet to pale green adjacent to the garnet margin.

43241	Plane polarized light	X38







4. Secondary pale coloured biotite after garnet, cordierite and K-feldspar.

5. Red-brown biotite of the microinclusions.

6. Red-brown biotite intergrown with muscovite in the Dover River Granite.

The biotites of types 1 to 3 have similar optical properties and composition. The three textural types include apatite, zircon and ilmenite in order of relative abundance. Two groups of apatite grains are enclosed by the biotite and are comparable to those found in the garnet. These are fine-grained (less than 0.1 mm.) apatite needles and subhedra up to 4 mm. in length (Plate 14). The larger apatite grains are also enclosed in the felsic minerals. The primary biotite of type 3 may change colour (and composition) adjacent to garnet phenocrysts (Plate 30), merging with the secondary biotite replacing the garnet. Along euhedral garnet and plagioclase margins the adjacent biotite, especially in the Boobyalla and Mt. Kerford Granites, commonly occurs as a symplectite with quartz (Plate 31). In sample 43221 the vermicular quartz rods, up to 0.1 mm. wide, form 10 percent of the area of the biotite grains.

The type 4 secondary biotites replace garnet, cordierite and K-feldspar. The maximum absorption colours of pale green and pale sea-green for the secondary biotites after garnet and cordierite respectively, are peculiar to those replaced minerals. The quartz-biotite symplectites which replace the K-feldspar are common in the vicinity of partially replaced garnet grains. The pale coloured biotite of the symplectites occurs as optically continuous outgrowths from red-brown biotite booklets.

The type 5, fine-grained (0.1 to 1 mm.) biotite, which is either intergrown with quartz or forms a mosaic with quartz, occurs in microinclusions (Plate 32). The microinclusions, which range in size from 3 to 10 mm., are surrounded by red-brown biotite subhedra. Under high magnification the inclusion texture is comparable to the hornfelsed Mathinna Beds (Plate 33) in which the quartz encloses minute rounded biotite grains. These inclusions, rarely exceeding 1 percent by volume, occur in all the aluminous granite

PLATE 31

Quartz-biotite symplectite adjacent to euhedral garnet margin. The biotite encloses zircon and apatite crystals.

43216	Plane polarized light	X55

PLATE 32

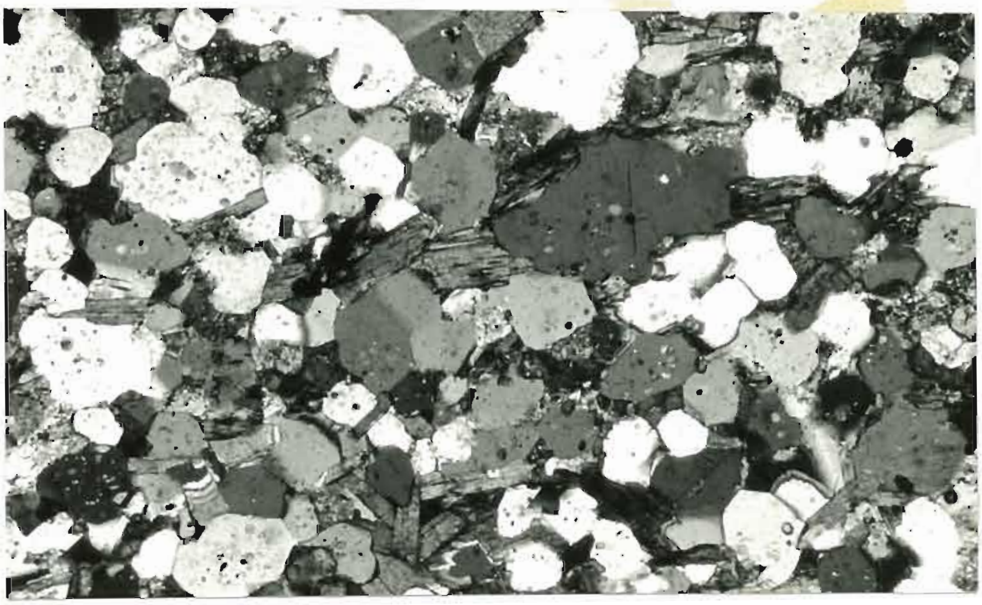
Mathinna Beds microinclusion composed of granular quartz and biotite. The microinclusion surrounded by igneous biotite may be a synneusis texture which formed during intrusion.

43166	Plane polarized light	X15.5

PLATE 33

Mosaic quartz and biotite in Mathinna Beds inclusion. Note the rounded biotite inclusions in the polygonal quartz grains. This texture is also found in the microinclusions.

43116	Crossed nicols	X77



plutons except the Hogans Hill Granite. Adjacent to a Mathinna Beds contact on Maria Island, up to 5 percent of the granite is composed of the microinclusions.

The Dover River Granite red-brown biotite (type 6) is intergrown with white-mica (Plate 34). This texture may be a primary intergrowth as the biotite pleochroism differs from that of the biotite replacing the cordierite in this rock, and the blocky form of the intergrowth is dissimilar to the wedging form of the secondary micas (compare Plates 34 and 29).

Chlorite, and to a lesser extent white-mica, replace biotite, particularly in the groundmass of the porphyritic rocks. The chlorite commonly encloses rutile needles and granular Fe-carbonate (Plate 35).

3.3.5 Feldspars

The feldspars occur in subequal proportions in these aluminous granites. Plagioclase is generally tabular and subhedral in most plutons, although in the groundmass of the granite porphyries it may be part of the granular mosaic or intergrown with the other felsic minerals and biotite. The K-feldspar phenocrysts or megacrysts are tabular and generally enclose all other phases. Like the plagioclase, the K-feldspar in the groundmass of the porphyries may form part of the granular mosaic, and both feldspars may enclose each other. The plagioclase also includes all other phases, but as it is not included in the garnet or cordierite it may not have been a near-liquidus phase. Phenocrysts of both feldspars include groundmass grains in the porphyries, especially K-feldspar which may also enclose graphic quartz. In the Boobyalla and Bicheno Granites glomeroporphyritic textures and embayed feldspars, as well as embayed quartz, are common. The plagioclase ranges in composition from An 50 to An 10. Normal and oscillatory zoning patterns surround the core which generally has a uniform composition. In the more calcic plagioclase grains the zoning tends to be complex with thin, cross-cutting zones. Core compositions as calcic as An 50 are confined to phenocrysts in the porphyry of the Key Bay Granite; however, the An 40 to An 45 range in composition is common

PLATE 34

Intergrown biotite and white-mica. Note that the intergrowths have tabular rather than wedge-shaped terminations which are shown in Plate 29.

43871 Plane polarized light X38

PLATE 35

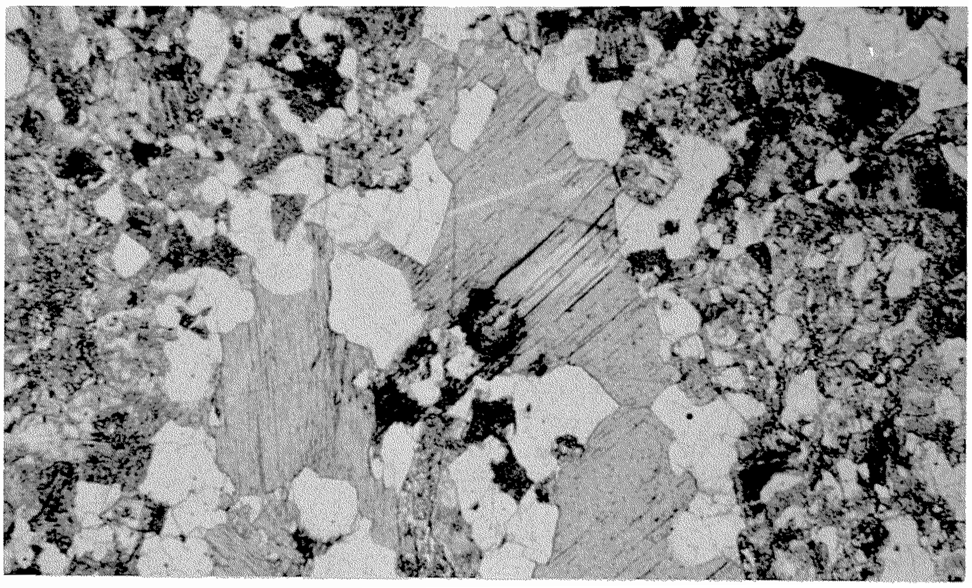
Rutile and Fe-carbonate in chlorite after biotite.

43161 Plane polarized light X132

PLATE 36

Intergrown white-mica and quartz after feldspars in the groundmass of a granite porphyry.

43169 Plane polarized light X15.5



to most plutons. In all plutons sodic rims (An 20 - An 10) are well developed especially adjacent to K-feldspar where myrmekite is also common. The K-feldspar of these granites is perthitic with a variety of perthite forms. The megacrysts are simply twinned and incipient to well developed cross-hatch twinning occurs in some plutons. Both feldspars are partially replaced by white-mica, the plagioclase in the core region by a felted mass of small grains, and the K-feldspar by larger ragged grains (up to 5 mm. wide). The degree of replacement by white-mica is greatest for the altered plutons and in some samples (43169) the groundmass has been replaced by coarse-grained white-mica and quartz (Plate 36). Densely clouded K-feldspar is uncommon in the unaltered granites, but in some cases cloudiness is spatially associated with exsolved albite (Plate 42). In the altered plutons the K-feldspar tends to be densely clouded with minute fluid (?) inclusions which are not individually resolved with an optical microscope.

3.3.6 Andalusite

Andalusite replaces cordierite (Plate 28) and garnet (Plate 23), but in the Boobyalla Granite subhedral grains up to 1 mm. long may have crystallized from the melt. Andalusite intergrown with the groundmass of the granite porphyries (Plates 37, 38) may also be igneous in origin. The andalusite is altered marginally and along cracks to fine-grained white-mica.

3.3.7 Secondary Phases

Biotite, white-mica and chlorite are the most abundant and widespread secondary minerals. In the pervasively altered garnet- and cordierite-bearing granitoids they are accompanied by tourmaline, fluorite and topaz. The tourmaline replaces K-feldspar (Plate 39) and occurs as large crystals and nodules, whereas the fluorite and topaz tend to replace plagioclase and biotite.

3.4 Mn-rich Garnets in Aplites and Pegmatites

Miyashiro (1955) distinguished between the almandine-pyrope garnets of calc-alkaline volcanics and plutonics, and the almandine-spessartine garnets

PLATE 37

Andalusite phenocryst partially including groundmass grains in a granite porphyry. The andalusite is replaced along margins and cracks by white-mica.

43223 Crossed nicols X75

PLATE 38

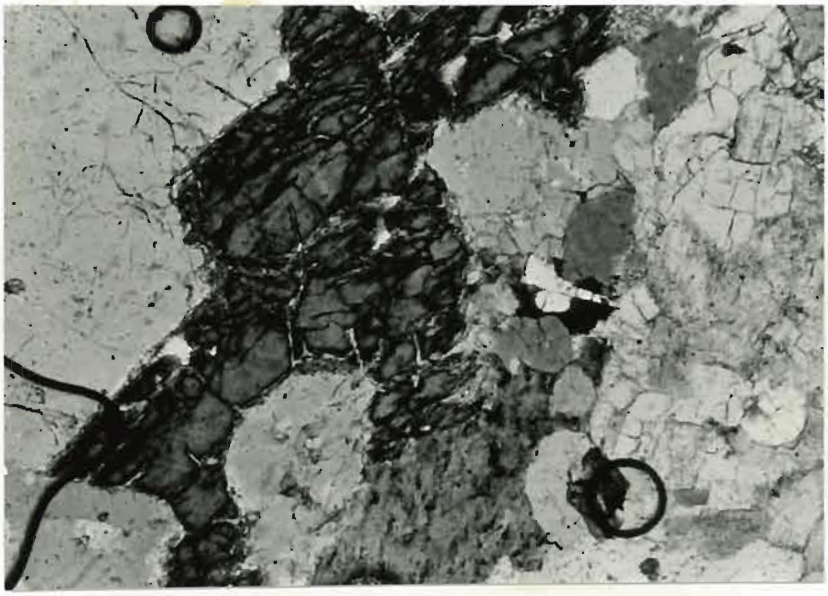
Andalusite possibly replacing the groundmass of a granite porphyry.

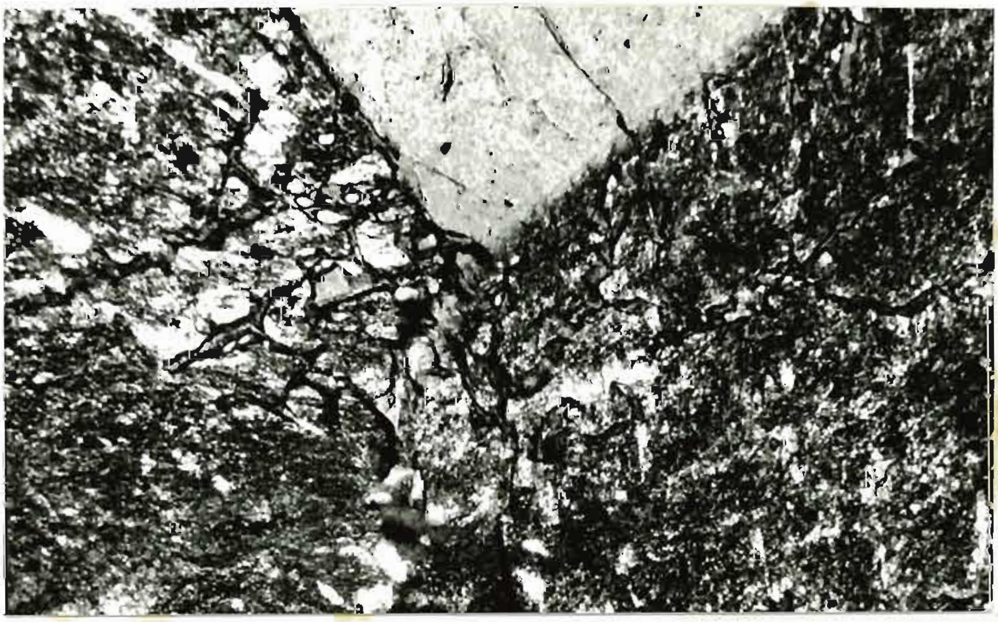
43180 Crossed nicols X69

PLATE 39

Tourmaline (high relief) replacing clouded K-feldspar.

43181 Crossed nicols X95





found in aplites and pegmatites, and in vesicles in calc-alkaline volcanics. Similarly in the Tasmanian rocks, the garnets of the large garnet-cordierite-biotite plutons differ from Mn-rich garnets in late-stage intrusive aplites, pegmatites and microgranites. Six late-stage garnet-bearing dykes have been studied: two pegmatitic dykes from eastern Tasmania (43293, 43294), a quartz porphyry from the Heemskirk Granite (43296, described by Green, 1963), two dykes from non-garnet-bearing plutons (43295, 43297), and one dyke from the Ansons Bay Pluton (43298).

The garnet is commonly anhedral, rarely replaced by white-mica or biotite, and is associated with quartz to the exclusion of the feldspars. The garnet forms up to 10 percent of the rock (43298) and rarely exceeds 3 mm. in diameter. Clouded K-feldspar, commonly carrying graphic quartz, and albitic plagioclase are the main feldspars. Chloritized biotite, tourmaline and zircon are accessory minerals in these rocks.

Spessartine-rich garnets as a widespread accessory phase do not occur in the large granitoid plutons in Tasmania, although Groves (1972b) records accessory (possibly secondary) spessartine-almandine garnets in the Lottah Granite at the Anchor Mine. Possibly the Rakeahua Granite (Appendix F) in New Zealand is one of the few large plutons in which these garnets occur as a prominent accessory. The Onahua Granite (43292) is another New Zealand body with widespread accessory spessartine-rich garnets.

3.5 Summary

The garnet-cordierite-biotite granites are intrusive, contact-aureole, largely post-tectonic granites. Within most plutons there is a range in rock types from equigranular rocks with low proportions of K-feldspar megacrysts to granite porphyries with up to 80 percent phenocrysts. Mafic mineral segregations are common and feldspar megacryst foliations are variably developed in most plutons. Mafic inclusions derived from the country rocks or deeper levels are uncommon except near the margins, although microinclusions of the

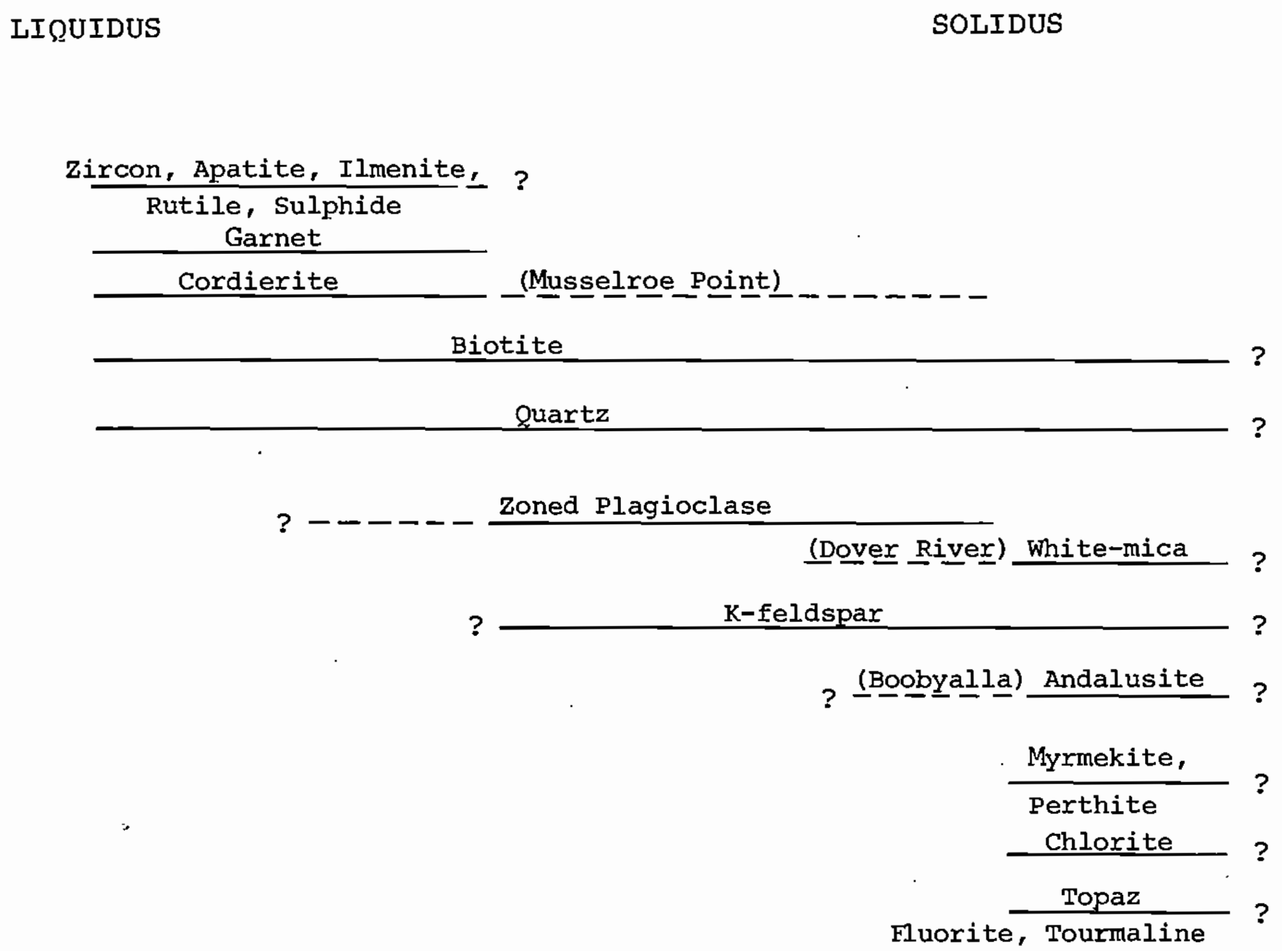


Fig. 3.4 Mineral parageneses for garnet-biotite and garnet-cordierite-biotite granites.

country rocks (less than 1% by volume) are widespread in most plutons. Field and petrographic evidence indicates that the crystallization of mafic minerals does not depend on the assimilation of the country rocks. This conclusion is supported by the fact that the garnet-bearing Hogans Hill Granite is entirely surrounded by the Mt. Kerford Granite and does not intrude the Mathinna Beds.

Inclusion relationships and reaction textures, and the supporting field evidence of mineral segregations, show that the mafic silicates crystallized at an early stage in the mineral parageneses. The general paragenetic relations of all the phases in the granites are illustrated in Figure 3.4.

In considering the origin of the garnet, cordierite and biotite, the following field and petrographic characteristics must be taken into account:

1. Early crystallization of these phases with the exception of the cordierite in the 'spotted' microgranites.

2. Euhedral form prior to subsolidus alteration.

3. Similar grain size (prior to alteration) of these phases in the equigranular and porphyritic variants of the same pluton, and similar grain size to other phases in the equigranular rocks or to other phenocryst phases in the porphyritic rocks.

4. Lack of similar garnet and cordierite crystals in inclusions or in the country rocks.

5. No supersolidus reaction textures between garnet and cordierite or other phases, except the replacement of garnet by biotite.

These features rule out xenocryst origins and characteristic 3 suggests igneous crystallization rather than a relict phase origin. The intergrown cordierite in the 'spotted' microgranites emphasizes the igneous crystallization of cordierite in this rock type. Igneous crystallization of garnet is also supported by compositional data (section 7.4.3.3).

CHAPTER 4

GEOLOGY AND PETROGRAPHY OF THE BIOTITE GRANITOIDS

4.1 Introduction

The biotite granites constitute the most widely spread and voluminous granitoids in Tasmania. They include the two largest plutons in the Blue Tier Batholith, the Mt. Pearson and Poimena Plutons (Figure 2.2), and all the plutons in north-western and western Tasmania. Modally most of the plutons are granites although some of the altered bodies with high albite contents are alkali-feldspar granites. The altered biotite granites are significant as they are the host rocks for the bulk of the Sn mineralization in Tasmania (Klomínský and Groves, 1970; Groves, 1972a, in press). Groves (1972a) has summarized the field features and petrography of the Meredith and Heemskirk Granites and the mineralized granitoids at Mt. Bischoff and Pine Hill in western Tasmania.

The petrography of the unaltered biotite granites will be described only briefly, as many aspects are similar to those of the garnet-cordierite-biotite granites discussed in Chapter 3. The petrography of the altered biotite granites is described in more detail as the secondary nature of the mineralogy has not been emphasized by previous workers.

4.2 Field Characteristics and Petrography of the Unaltered Biotite Granitoids

The biotite-bearing unaltered plutons occur as massive, inclusion-poor granites exposed over large areas. Although the biotite-bearing, Mathinna Beds inclusions are relatively rare, they are commonly concentrated along contacts (up to 5% by volume). K-feldspar megacryst foliations are widespread and variably developed. Groves (1968) documents up to three foliations in small areas of the Poimena Pluton. The three foliations cut each other suggesting that at least the more recent foliations have formed in imposed stress fields (Berger and Pitcher, 1970). In the biotite granites a well developed penetrative foliation, in which all phases are deformed, is relatively rare compared with the hornblende-biotite granodiorites. Considering all the biotite granite plutons, biotite-rich layers are widespread, although irregularly distributed in individual plutons. The nature of the layers varies from short, steeply dipping, discontinuous individual layers to multiply layered complexes (for example the Corner Granite - Plate 40). The range of layered structures is similar to those found in the garnet-cordierite-biotite granites. The main textural variation within these plutons is in the size and proportion of K-feldspar megacrysts and grain size of the groundmass. The megacrysts range in grain size from 20 to 300 mm. and the groundmass grain size varies from 3 to 15 mm. . K-feldspar megacrysts form up to 50 percent of the granitoid but are commonly less than 10 percent. The biotite content ranges from 5 to 25 percent.

The paragenesis of the primary minerals in the biotite granites is biotite (and apatite and zircon), plagioclase, quartz and K-feldspar. Most rocks have granitic textures with subhedral biotite and plagioclase and in some rocks subhedral quartz crystals. When deformed, the biotite in these rocks displays kink bands and healed kink bands, and is recrystallized to small aggregates which are comparable to those in the strongly deformed hornblende granodiorites. The K-feldspar associated with strongly kinked biotite has well developed cross-hatch twinning, which in the Heemskirk Granite Brooks (1966b) correlated with proximity to faults. The biotite has red-brown maximum pleochroism and commonly includes two generations of apatite, similar to those in the garnet-cordierite-biotite granites. Quartz-biotite symplectites, replacing K-feldspar as a fringe around primary biotite grains, are common in many plutons and may be a subsolidus texture. In the garnet-bearing granites this texture is related to garnet replacement, but similar breakdown reactions providing Fe and Mg

PLATE 40

Biotite layers paralleled by K-feldspar megacrysts in the Corner Granite, Long Island (ER/850.311).

PLATE 41

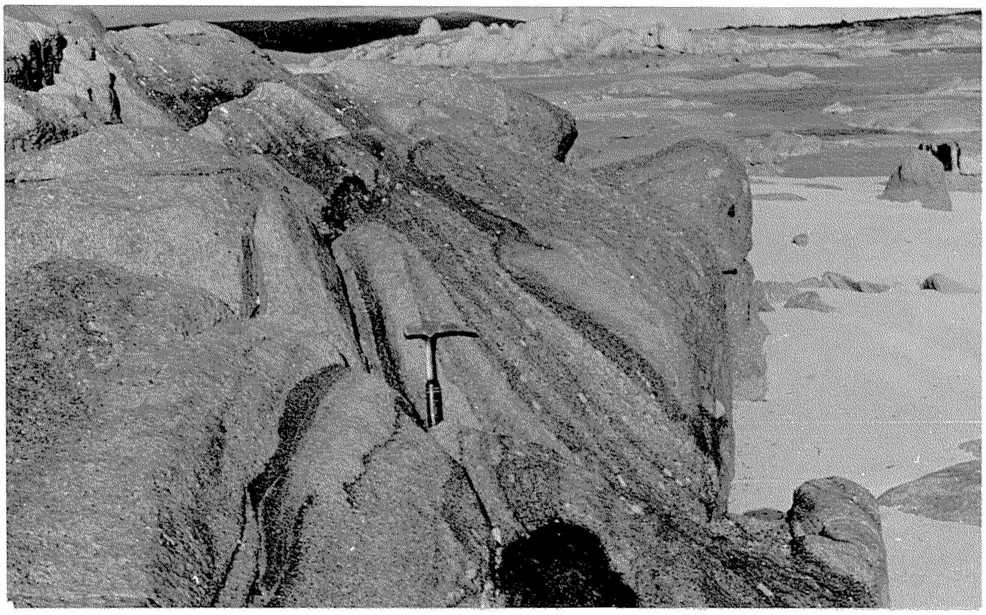
Plagioclase phenocryst with a zone of quartz inclusions which mimics the shape of the altered, euhedral core. This texture is comparable with the quartz inclusion zone in the garnet grain in sample 43252 (Plate 10).

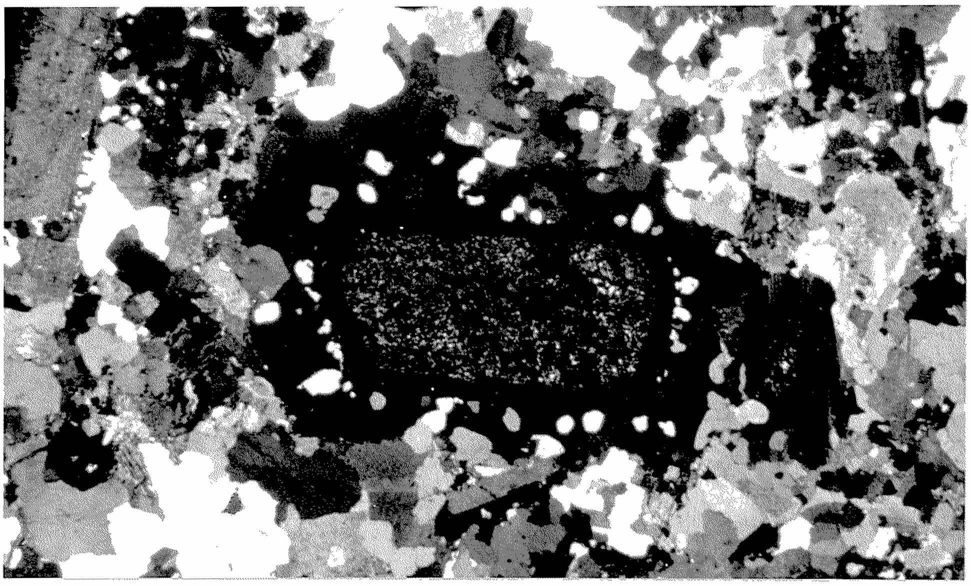
40531 Crossed nicols X15.5

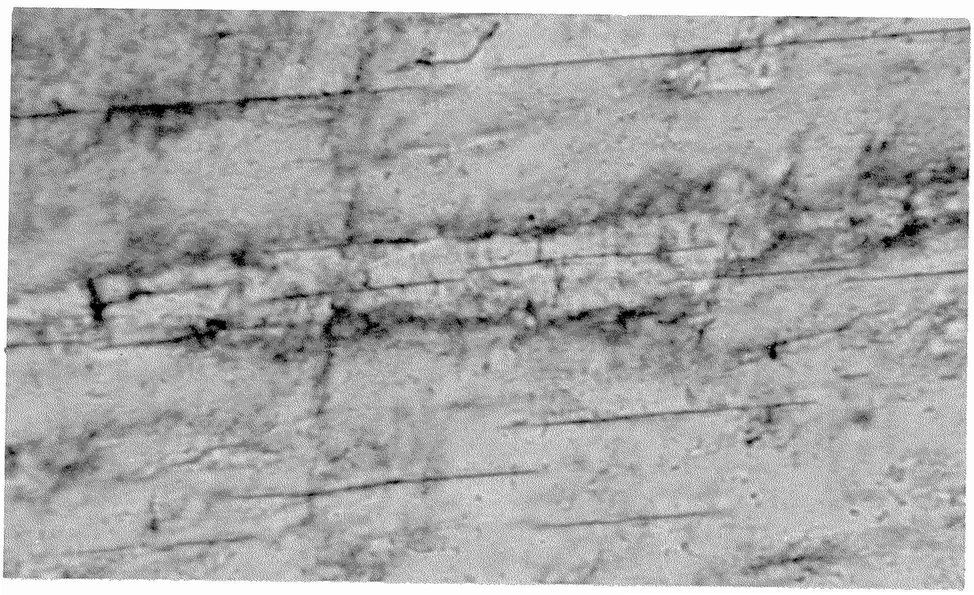
PLATE 42

Perthitic K-feldspar with fluid (?) inclusions adjacent to exsolved albite.

40528 Plane polarized light X385







for the secondary biotite are not evident in these granites. The plagioclase subhedra have similar zoning patterns and compositions to those in the garnet-cordierite-biotite granites. In Plate 41 the core of a plagioclase grain in a biotite granite porphyry at Coles Bay, is surrounded by a zone of quartz inclusions, similar to the zoned garnet in Plate 10. The K-feldspar of the biotite granites is perthitic and displays variable cloudiness which in many cases is spatially associated with the perthite (Plate 42). Chlorite after biotite, and white-mica after the feldspars are the common secondary phases. The white-mica tends to replace plagioclase as a felted mass mainly in the plagioclase core, whereas the white-mica after K-feldspar is coarser grained although generally less than 2 mm. in width.

The biotite granites, adjacent to the younger, pervasively altered biotite granite plutons, are commonly altered over distances up to 10 m. from the contact. The alteration gives rise to a pink colouration which in thin-section is seen as a marked increase in cloudiness of the K-feldspar. Accompanying the feldspar alteration is the development of secondary biotite, chlorite, topaz, tourmaline, fluorite and carbonate. The primary biotite may be recrystallized (Plate 43).

4.3 Field Characteristics and Petrography of the Altered Biotite Granitoids

4.3.1 Introduction

The petrographically altered biotite granite plutons are distinguished from the unaltered biotite granite plutons by a pervasive alteration throughout each pluton. The intensity of the alteration varies widely between and within plutons. The alteration commonly takes the form of a pink colouration which in thin-section is seen as clouded K-feldspar. In the slightly altered rocks the mineralogy and textures are similar to those in the unaltered biotite granites. Increasing intensity of alteration is marked by an increase in the proportion of secondary phases, including white-mica, biotite,

PLATE 43

Recrystallized biotite in contact metamorphosed Poimena Granite.

40558 Crossed nicols X48

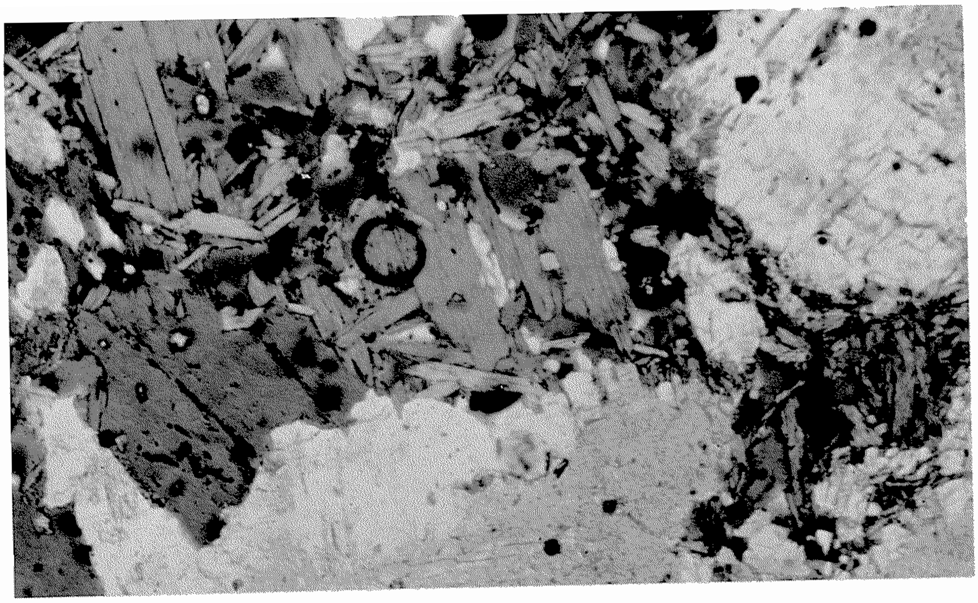
PLATE 44

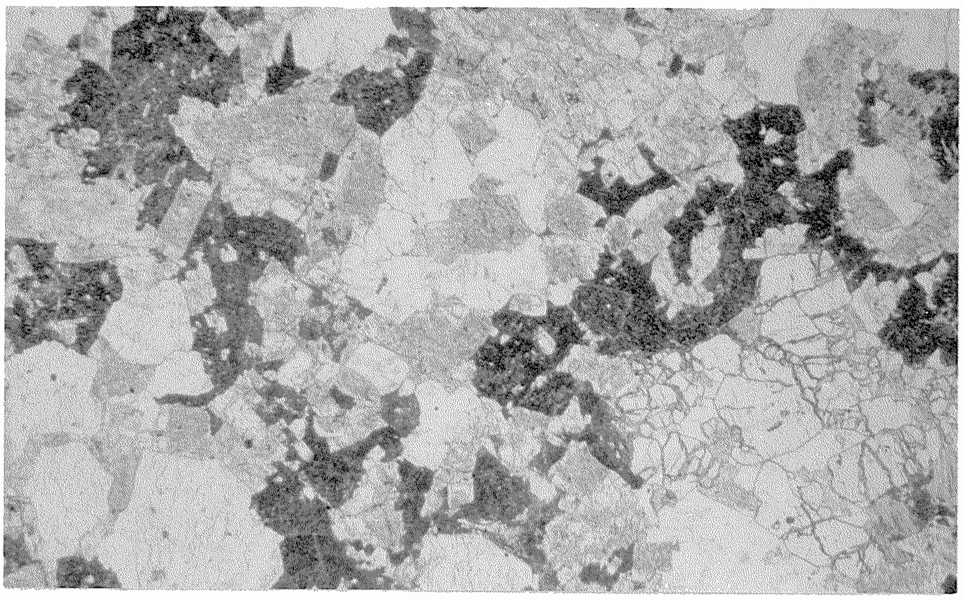
Undulating biotite layers parallel to recessive pegmatite layers, in the Rooks River Granite (ER/966.320).

PLATE 45

Medium-grained, subequigranular altered biotite granite. The dark phase is clouded K-feldspar. The plagioclase is subhedral and partially clouded, the topaz has high relief, and quartz is the clear phase.

40511 Plane polarized light X15.5





topaz, quartz and carbonate, which replace the igneous minerals. Greisen is the end-product of the alteration process. The status of the feldspars in the strongly altered biotite granites, as igneous or secondary phases, is not clear on petrographic grounds.

The following comments on the field characteristics and petrography of altered biotite granites are based on the examination of rocks from the Mt. Paris, Lottah, Rooks River, Coles Bay and Constable Creek Granites.

4.3.2 Field Characteristics

The principal field characteristics of the altered granitoids are their cream to red colouration, variety of equigranular to porphyritic textures within each pluton and low mafic inclusion and biotite (less than 5%) contents. The variety of textures within a single pluton can be extreme with wide variation in the grain size, the proportion and the nature of the phenocrysts. Since rock type changes are frequent and contacts with variable attitudes are commonly gradational, mapping within these plutons is difficult (Rooks River Granite - Appendix E). Minor lensoid aplites and pegmatites, from 10 mm. to 2 m. wide, also add to the complexity of rock types. Biotite-rich layered structures are rare (Plate 44). Foliations defined by, and segregations of, K-feldspar megacrysts in both the porphyries and even-grained rocks are common. A feldspar foliation defined by zoned plagioclase and K-feldspar megacrysts is widespread in the Rooks River Granite and because the early crystallized plagioclase is aligned, this foliation probably developed during intrusion. The foliations defined by K-feldspar alone may reflect regional stress fields, at least in some areas where this feldspar has crystallized across rock type contacts (Beattie, 1967).

A notable exception to these general field features is the Heemskirk Granite of western Tasmania. Although variable on a small scale, this pluton is divisible into red and white granite types, with the red-type forming a subhorizontal undulating layer capping the pluton and overlying the white-type (Klomínský, 1971). The so-called white granite is comparable to the cream coloured altered granites of eastern Tasmania, although it carries a higher proportion of biotite-rich inclusions (Brooks and Compston, 1965).

4.3.3 Petrography

In the slightly altered biotite granites the mineral paragenesis is similar to the parageneses of the biotite and garnet-cordierite-biotite granites. The characteristic textural feature of these rocks is the even-grained, granular textures of the medium-grained granites and the fine-grained groundmass of the porphyritic granites. The equigranular texture is dominated by quartz, plagioclase and K-feldspar which tends to include all other phases. A significant textural component in the least altered biotite granites is the occurrence of widespread miarolitic cavities. In general, the miarolitic cavities are relatively common in rocks with an aplitic groundmass and in minor pegmatites. The cavities may be filled with amorphous compounds (Plate 46) or with minerals such as axinite (Plate 47), Fe-carbonates and chlorite. Thin-section evidence for deformation is restricted to the more strongly altered rocks, in which the feldspars have well developed grain boundary granulation, and wedge-shaped twins are common in the albite. The biotite and white-mica grains are rarely kinked.

Biotite is the only mafic mineral (from 0.5 to 8%) in these rocks and is significant because of its role as a carrier for trace Sn. A range of textural features and pleochroism correlate with the degree of alteration. In the least altered plutons, such as the Hogans Hill Granite, areas in the Rooks River Granite (Appendix E) and areas in the Mt. Paris Pluton, the maximum biotite pleochroism is red-brown and comparable to the biotite in the unaltered biotite and garnet-cordierite-biotite granites. In these rocks, the fine-grained biotite and the margins of the larger biotite grains are commonly altered to chlorite (40548). Subhedral booklets are

PLATE 46

Angular miarolitic cavity bordered by subhedral quartz and K-feldspar. The structure is filled with fine-grained micas and possibly amorphous compounds.

43841 Crossed nicols X95

PLATE 47

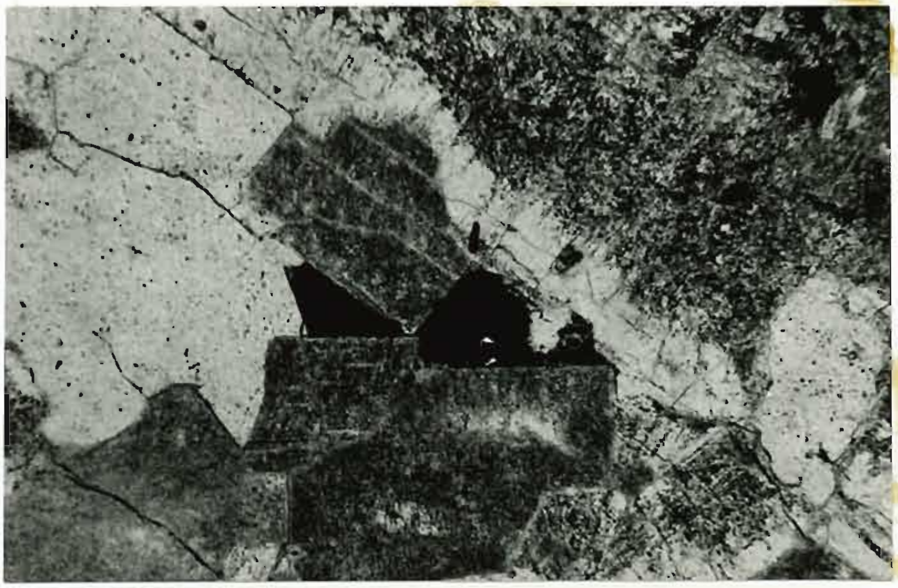
Miarolitic cavity bordered by subhedral quartz and K-feldspar. A single axinite grain has crystallized within the cavity and is surrounded by amorphous compounds.

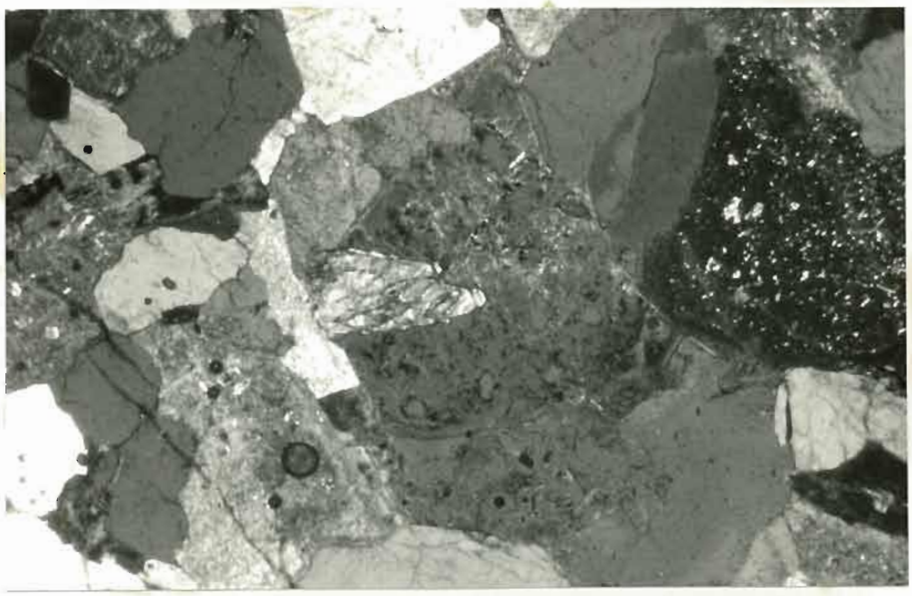
43800 Crossed nicols X15.5

PLATE 48

Pale brown, ragged biotite replacing densely clouded and cleaved K-feldspar. Parallel, blocky albite inclusions in the K-feldspar have not been replaced by the biotite.

40514 Crossed nicols X95





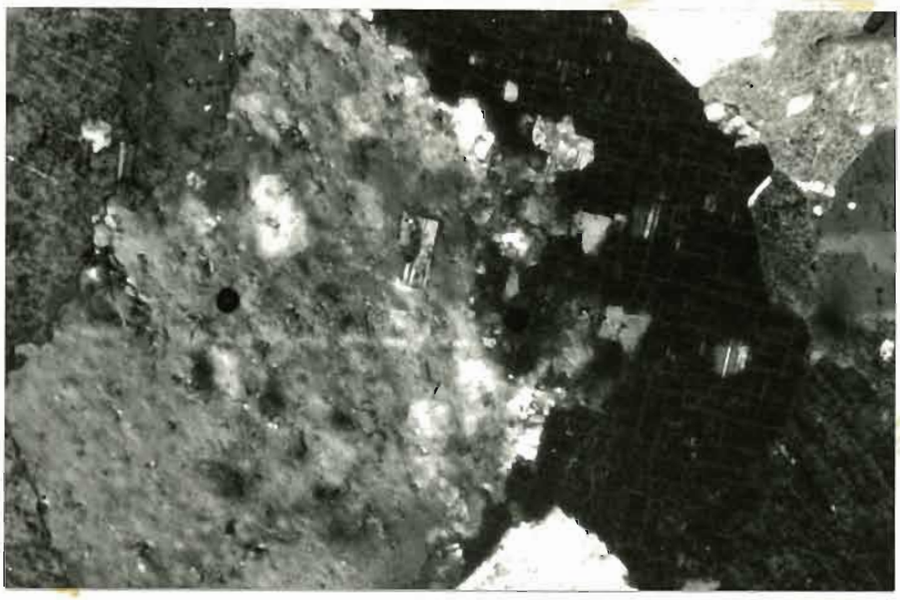


PLATE 49

Pale brown biotite replacing secondary topaz.

40553 Crossed nicols X95

PLATE 50

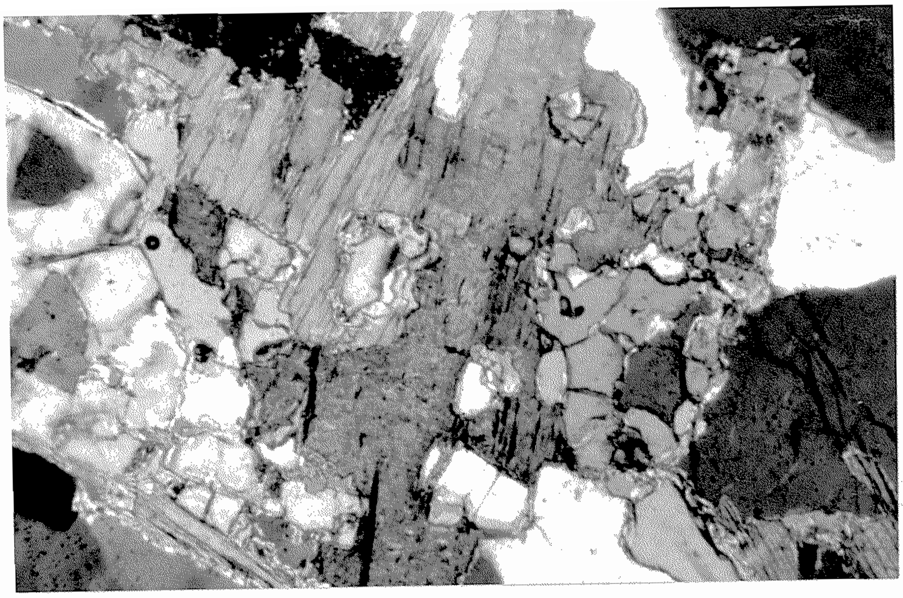
White-mica and quartz replacing K-feldspar in the groundmass of a micro-granite. The white-mica encloses quartz from the groundmass, its equi-dimensional form distinguishing it from the narrow, sinuous secondary quartz (top right) along the margin of the white-mica.

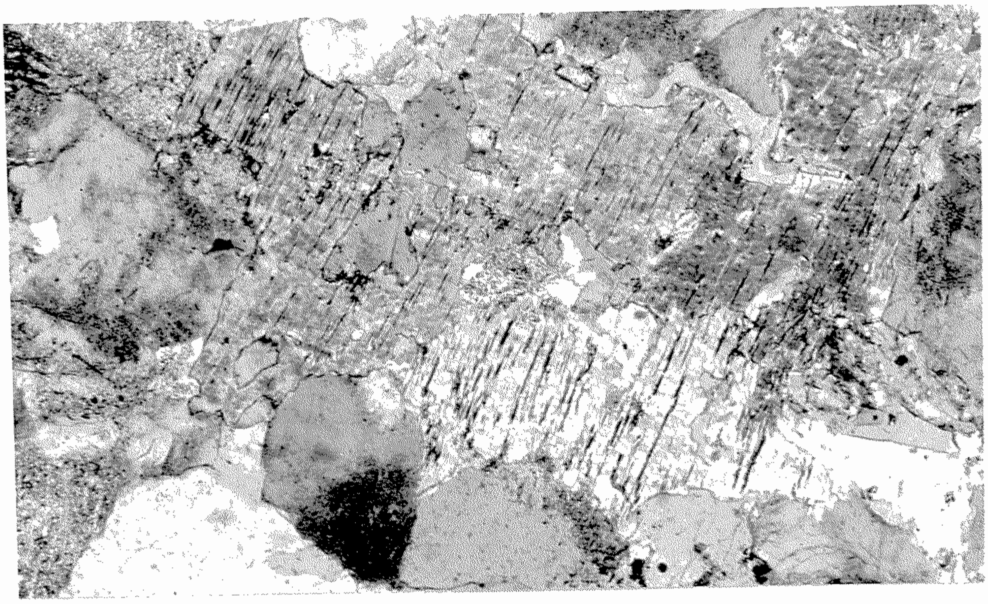
43807 Crossed nicols X73

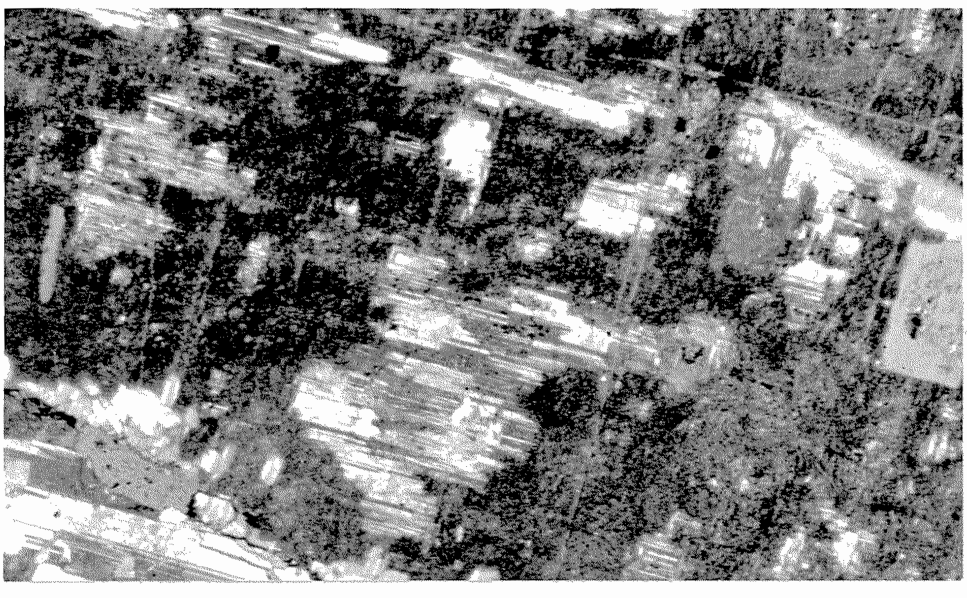
PLATE 51

Blocky, albitic perthite exsolved from clouded K-feldspar.

40530 Crossed nicols X47







common in the least altered rocks, whereas in the more altered rocks, such as the Lottah Granite, the biotite has a ragged form, replacing red-brown biotite, K-feldspar, quartz and possibly topaz (Plates 48, 49). The secondary biotite is also characterized by its pale colour, with maximum pleochroic colours from pale greenish-yellow to pale brown. In the secondary biotite, pleochroic haloes about inclusions and along cleavages and grain boundaries are common. The secondary nature of the biotite in the moderately altered intrusions has not been considered by previous workers in their discussion of the trace Sn distribution in these rocks.

The altered biotite granites have been referred to as biotite-muscovite or two-mica granites (Groves, 1972b, in press; Groves and Taylor, 1973). There is little petrographic evidence for an igneous origin for the white-mica. Coarse-grained (greater than 0.5 mm.) white-mica in the least altered rocks replaces original biotite and K-feldspar (Plates 36, 50). Secondary, fine-grained white-mica, which occurs in varying proportions in most altered granites, partially replaces all the primary phases in the strongly altered rocks. Within the strongly altered Lottah Granite the fine-grained white-mica occurs as sheaves (possibly sericite) and rosettes (possibly pyrophyllite) which replace K-feldspar (40511, 40514, 40515). In many thin-sections of the strongly altered rocks, distinction between pale-coloured biotite and white-mica is difficult.

The K-feldspar occurs as clouded, simply twinned, perthitic, subhedral to anhedral grains. The density of minute fluid inclusions (Plates 45, 51), which gives rise to the cloudiness in thin-section, increases with increased alteration and this may account for the range in colour of the K-feldspar from light pink to dark red. Two generations of plagioclase are distinguished in the slightly altered porphyritic rock types. The phenocryst plagioclase, with core compositions up to An 30, is normally zoned, and altered to a felted mass of white-mica in the core. Albite rims on the phenocrysts are rarely altered. The anhedral, equidimensional plagioclase of the groundmass is partially clouded by small inclusions, which are generally not as fine-grained or densely packed as those in the K-feldspar. The composition of the groundmass plagioclase ranges from An 10 to An 20 and is rarely zoned except for an unaltered, clear, albite rim comparable to the rim around the phenocrysts. In the medium-grained, equigranular rocks, the two generations of plagioclase cannot be distinguished, but most grains have high-Ca cores, and in some samples smaller grains are comparable to the groundmass plagioclase of the porphyries.

Petrographic evidence for the replacement of plagioclase by K-feldspar (Spry and Ford, 1957) was not found in this work, the wide range of feldspar intergrowths (Plates 51, 52) being interpreted as exsolution phenomena, in some cases possibly controlled by deformation. This observation does not exclude the possibility that some proportion of both feldspars are secondary and this is highly likely for the strongly altered, albite-rich Lottah Granite at the Anchor Mine (Plate 45). Exley and Stone (1964) and Stone (1975) suggest that the feldspar mineralogy and texture of biotite granites in south-west England largely reflect the post-magmatic alteration. Further evidence for recrystallization and the overlap between magmatic and post-magmatic processes is found in a 0.5 mm. wide quartz (-topaz) vein which cuts K-feldspar, but is optically continuous with the quartz grains of the granite (Plate 53). Also quartz appears to replace (Plate 54) or is replaced by K-feldspar in several samples. Jahns and Burnham (1969) emphasize that the aqueous phase exsolved from a granitic melt will react at lower temperatures with the previously crystallized igneous phases.

Topaz is a widespread secondary phase (up to 5%) which in some samples appears to replace albite (Plate 55). The topaz is replaced by white-mica, amorphous compounds, pale biotite (Plate 49) and rarely by carbonate. Carbonate minerals occur as a secondary phase mainly after plagioclase, and Groves and Taylor (1973) record interleaved carbonate and white-mica in greisens. Tourmaline is an ubiquitious, although erratically distributed,

PLATE 52

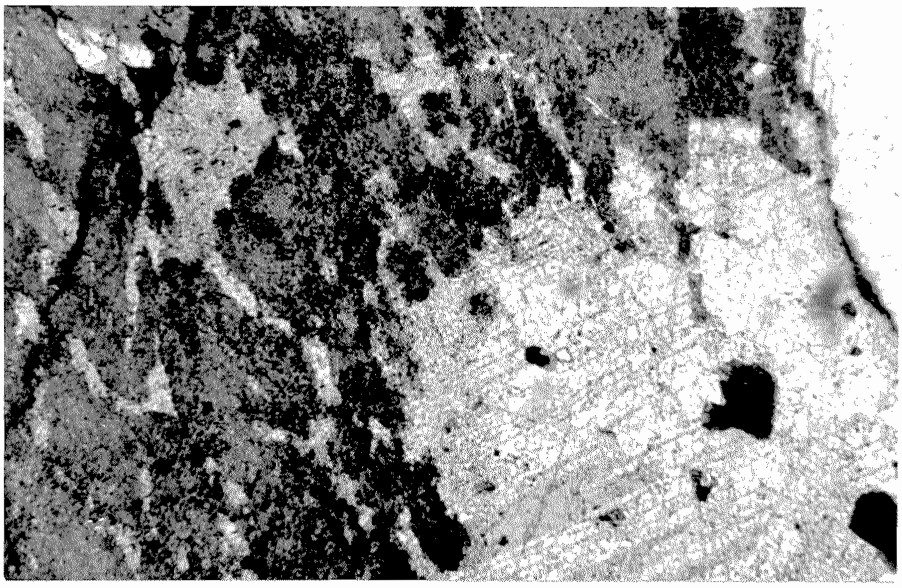
Albite grain in optical continuity with perthitic albite exsolved from clouded K-feldspar. This texture may lead to a clear separation between the albite and the K-feldspar with the appearance of primary magmatic crystallization.

40536 Crossed nicols X95

PLATE 53

Quartz from a quartz-topaz vein cutting clouded K-feldspar and quartz. The quartz in the vein is in optical continuity with the apparently primary quartz of the granite.

40584 Crossed nicols X15.5



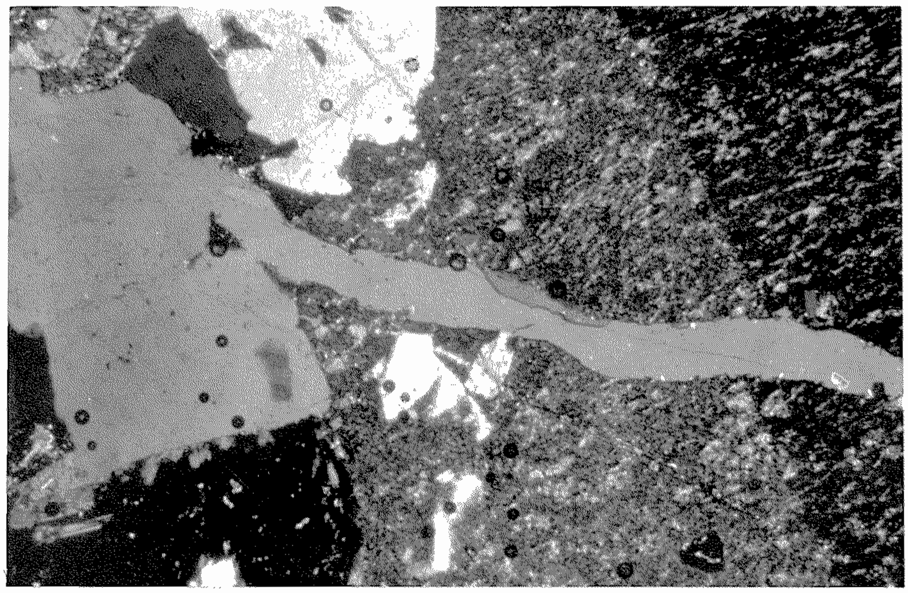


PLATE 54

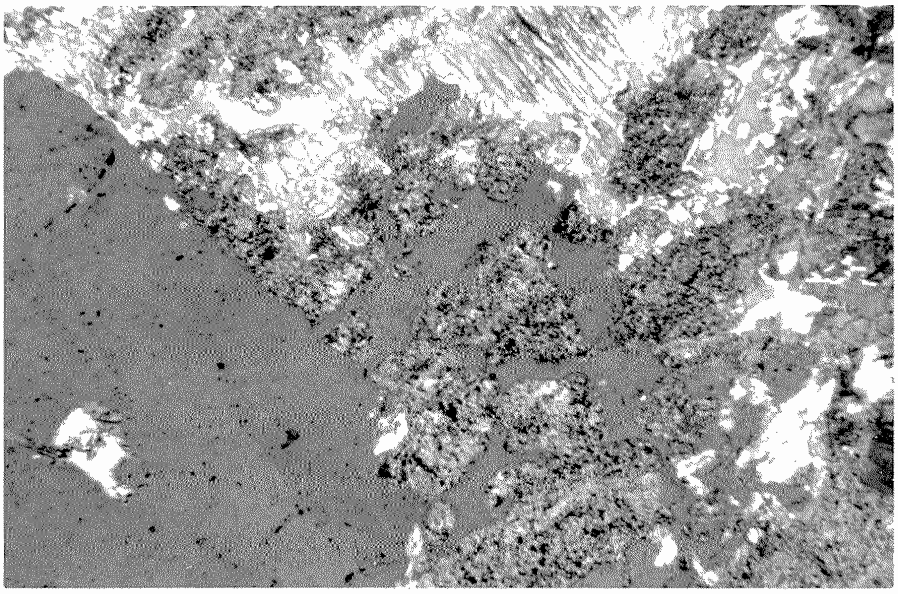
Quartz and biotite replacing clouded K-feldspar. Possibly the K-feldspar is replacing the quartz.

40512 Crossed nicols X15.5

PLATE 55

High relief topaz possibly replacing albite. The topaz is replaced along margins and cracks by fine-grained white-mica.

40553 Crossed nicols X95



accessory in many of the altered plutons and commonly occurs as radiating nodules from 10 to 500 mm. in diameter. Tourmaline is a characteristic accessory mineral in the Heemskirk Granite and tends to be concentrated in the white granite near its boundary with the red granite (Klomínský, 1971). The Fe-Ti oxide content is low in these rocks and cassiterite is rarely seen in hand specimen or thin-section.

CHAPTER 5

GEOLOGY AND PETROGRAPHY OF THE HORNBLENDE - BIOTITE GRANITOIDS

5.1 Introduction

Devonian, contact-aureole, hornblende-biotite granitoids are restricted to eastern Tasmania (Figure 1.2). The major hornblende-biotite plutons are confined to the Scottsdale and Blue Tier Batholiths and to west-central Flinders Island. Due to its similar composition the hypersthene-bearing St. Marys Porphyry is also included in this group. In general the hornblende-biotite granitoids are granodioritic in composition, although predominantly granodioritic plutons may include areally restricted biotite granites. In the following sections a brief summary of the characteristics of the hornblende granitoids is given.

5.2 Field Characteristics and Petrography

Detailed field and petrographic descriptions of the hornblende-biotite granitoids are restricted to those of the Blue Tier Batholith (Groves, in press; Cocker, 1976) and at Bridport in the northern area of the Scottsdale Batholith (Skrzeczynski, 1971). These rocks are generally massive, medium-grained and non-porphyritic. The Scamander Tier Granodiorite (Cocker, 1976) is a distinctive K-feldspar, quartz, hornblende, plagioclase and biotite porphyry which intrudes the George River Granodiorite and the Mt. Pearson Pluton. Longman (1966) also records granodiorite porphyries in the south-western portion of the Scottsdale Batholith.

The relative abundance of inclusions, especially dioritic inclusions, is a distinctive macroscopic feature of these rocks. Rounded hornblende-biotite diorite inclusions, which are commonly flattened in the foliation, are restricted to the hornblende-biotite granitoids and are distinguishable from the subangular, hornfelsed Mathinna Beds inclusions. The latter inclusions are common along contacts and rarer within plutons, although no quantitative study of the proportion of inclusions throughout any pluton has been made. It appears that many inclusion swarms may have been generated by the breakdown of larger inclusions (Plate 56), although concentration of small (less than 300 mm. diameter) inclusions by flow processes, suggested by the mafic mineral layering around swarms (Plate 57), is also a possibility.

Discontinuous mafic mineral layers are common in the hornblende-biotite granodiorites, and subhorizontal layering is a characteristic field feature in the northern area of the Scamander Tier Granodiorite (Cocker, 1976). The subhorizontal layering is consistent with the gravitational separation of the early crystallized phases, whereas the steeply dipping biotite layers in the southern area of this pluton may have formed by crystal sorting during intrusion. As the K-feldspar occurs as embayed phenocrysts in chilled margins of the Scamander Tier Granodiorite and also encloses all other phases, the alignment and segregation of this phase may reflect both early crystal sorting during intrusion, and late stage crystallization in a regional stress field (Berger and Pitcher, 1970). In other granodiorite plutons the discontinuous, steeply dipping, mafic mineral layers are commonly at high angles to the penetrative mineral foliations discussed below.

In the hornblende-biotite granodiorites the earliest period of deformation has the form of a steeply dipping foliation defined by the alignment of mafic and felsic minerals. The intensity of the foliation is variable within each pluton, and is commonly well developed near the pluton margins (Gee and Groves, 1971, 1974; Skrzeczynski, 1971). In the foliated margins the inclusions tend to be ellipsoidal in shape with their long axes parallel, or at a slight angle, to the foliation trend. Berger and Pitcher (1970) suggest that the angular discordance is in response to the contrast in size, shape and ductility of the host and the inclusion.

PLATE 56

Partially ruptured hornblende diorite inclusion in the Coles Bay Granodiorite (FP/103.375). The granitoid vein extends 2 m. into the inclusion. The disrupted margin of this inclusion is similar to inclusion swarms throughout the granodiorites.

PLATE 57

Inclusion swarm bordered by biotite layers in Cape Sir John Granodiorite (ER/837.249).

An extreme development of this foliation in and adjacent to a fault zone is described by Groves and Jennings (1973). The truncated nature of the foliation adjacent to some contacts is used as evidence for relative ages (Gee and Groves, 1971). A second phase of deformation, which is common to the granodiorites, cuts the foliation and has the form of irregularly distributed, narrow (1 to 5 mm.), dark green coloured, curved crush zones (Cocker, 1976). Short displacements (up to 200 mm.) are common (Plate 58). Healed movement zones may be common in the granodiorites, but require structures such as mineral layering for the displacement to be preserved. In Plate 59 the biotite layers are faulted, but beyond the layers there is no evidence of the movement.

The contact-metamorphic assemblages of the hornblende-biotite granodiorites are similar to those of the biotite and garnet-cordierite-biotite granites. Gee and Groves (1974), Marshall (1969) and Skrzeczynski (1971) have briefly described three contact metamorphic aureoles. The Bridport contact metamorphic aureole includes a narrow contact-migmatite zone in which cordierite-biotite granite leucosomes are prominent (Plate 60). This is interpreted as partial melting of the pelitic Mathinna Beds, giving rise to an aluminous magma which crystallized cordierite. The igneous cordierite has a grain size and texture different from those of the metamorphic cordierite and clearly is not a refractory, contact metamorphic phase in the leucosomes. Cordierite and garnet do not occur in the hornblende-biotite granodiorites even where the proportion of Mathinna Beds inclusions is locally high near contacts (Plate 61). This suggests that contamination of the granodiorites was not sufficient to crystallize the aluminous phases.

In thin-section the hornblende-biotite granodiorites are composed of euhedral to subhedral biotite and hornblende, euhedral to subhedral, multiply zoned and twinned plagioclase, interstitial K-feldspar and anhedral, undulose quartz. Accessory minerals common in these rocks include apatite, sphene, zircon, orthite (Plate 62) and Fe-Ti oxides. The mafic minerals

PLATE 58

Hornblende diorite inclusion displaced along narrow cataclastic zones in the Coles Bay Granodiorite (FP/105.377). The crush zones commonly form an irregular net and are unrelated to foliation or joint patterns.

PLATE 59

Biotite layers displaced by healed fault in the Unicorn Point Granodiorite (ER/727.371).

PLATE 60

Cordierite-biotite migmatitic granite from the contact-migmatite zone of the Bridport Granodiorite (59/278.512). Cordierite grains up to 30 mm. wide occur in the leucosomes.

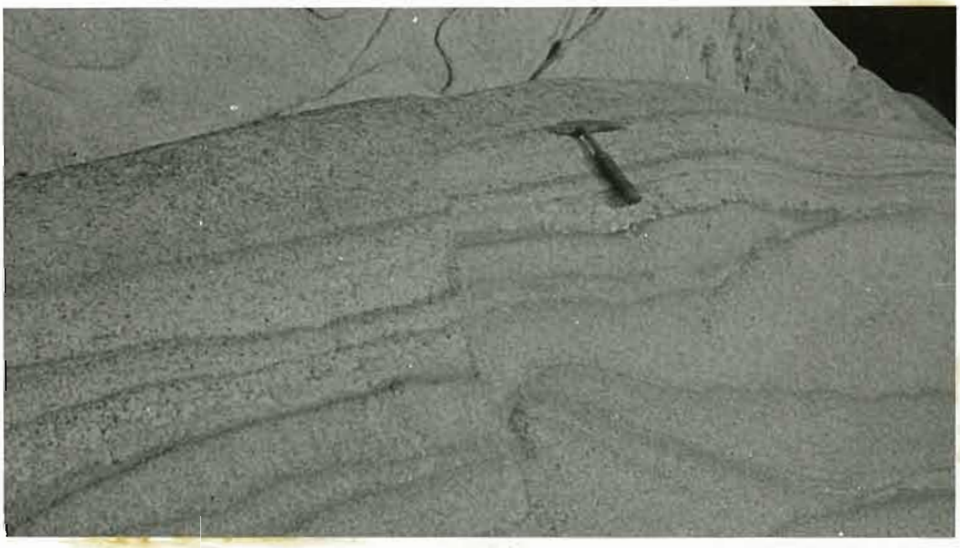


PLATE 61

Inclusion swarm and complex biotite layering in granodiorite adjacent to the main Badger Island Granodiorite contact (ER/768.369).

PLATE 62

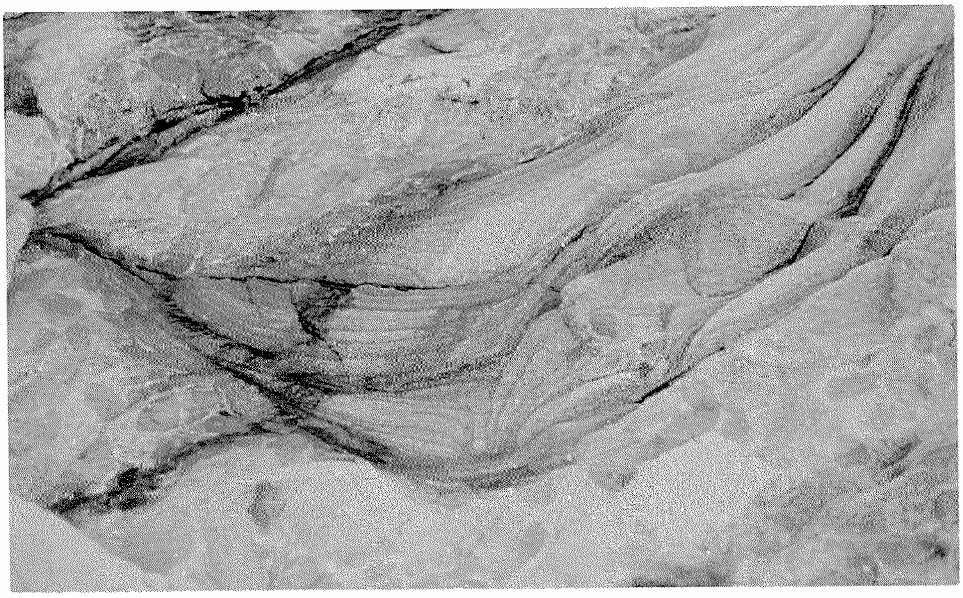
Zoned and embayed orthite enclosed in zoned and twinned plagioclase. Note the radial crack pattern in the plagioclase centred on the orthite.

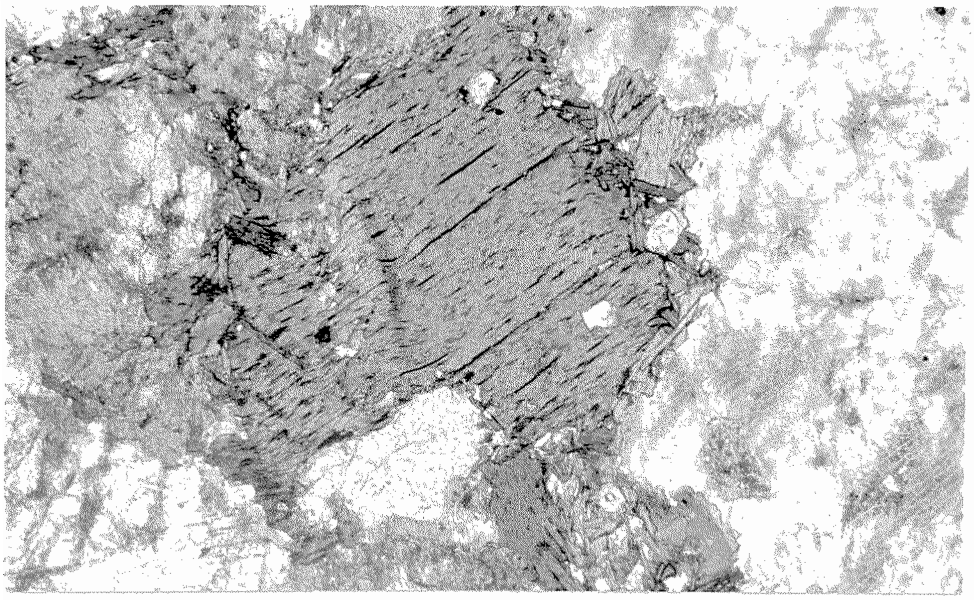
43901 Crossed nicols X95

PLATE 63

A kinked and partially recrystallized biotite grain from a granodiorite with a well developed cataclastic foliation.

43097 Plane polarized light X52





commonly occur as aggregates, possibly as microinclusions from the breakdown of larger dioritic inclusions. The pleochroism of both minerals is pronounced. The biotite pleochroism ranges from dark green to dark brown, distinguishing it from the reddish-brown, Fe-rich biotites in the granite plutons. The plagioclase ranges in composition from andesine-labradorite cores to albite rims, and has well developed oscillatory zoning sequences, which commonly encompass up to three grains in a synneusis relationship. Patchy zoning in plagioclase cores is relatively common. K-feldspar and quartz tend to be late in the paragenesis, although textural relationships are not always unequivocal. The foliation in thin-section is defined by the alignment of mafic minerals, and by elongate mosaics of quartz grains, annealed with 120° triple point junctions. Most of the other minerals show deformation effects with prominent kink bands (Ethridge and Hobbs, 1974) and recrystallization of biotite (Plate 63), and bent and fractured plagioclase grains. The common occurrence of cross-hatched twinning in K-feldspar is probably the result of the deformation. Under subsolidus conditions chlorite and muscovite have partially replaced biotite, and biotite and epidote have partially replaced feldspars. When altered by hydrothermal fluids, the feldspars are clouded with the plagioclase commonly replaced by fluorite and epidote and the biotite extensively chloritized.

The hypersthene-bearing St. Marys Porphyry has the form of a thick, intrusive sheet (Walker, 1957; McNeil, 1965). Sanidine, quartz, plagioclase and biotite accompany hypersthene as phenocrysts, set in a K-feldspar, plagioclase and quartz groundmass. Orthopyroxene is not found in any other granitoid unit in Tasmania.